A DECISION MAKING MODEL FOR DESIGNING TURNKEY HOUSING

Thomas Peter Connelie

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Thomas Peter Connelie

BCE, University of Dayton, 1963

A thesis submitted to the Faculty of the Graduate School of the University of Colorado in partial fulfillment of the requirements for the degree of

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A Decision Making Model for Designing Turnkey Housing

Thesis directed by Associated Professor Phillip F. Ostwald

This thesis includes the development of a model for selecting design and engineering features to be included in the design proposal for turnkey housing projects. A scoring system is developed to determine a weighted score for each alternative design feature and the model maximizes the evaluation score using a computerized BALAS zero-one algorithm. The constraints include the cost limitation and design criteria.

This abstract is approved as to form and content.

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CHAPTER I

MILITARY FAMILY HOUSING PROCUREMENT

The procurement of all goods and services by the various branches of the United States military establishment is regulated by the Armed Services Procurement Regulations (ASPR), a set of administrative rules having the effect of law. Because of the wide range of goods and services required by the military, these rules cover a broad range of procurement methods with restrictions on the use of each type. Construction of facilities is identified as a particular type procurement with competitive bidding based on government furnished plans and specifications leading to a fixed price lump sum contract clearly identified as the preferred procedure.[1] This is certainly the most widely used method for contracting for the construction of facilities but by no means is it the only one. The regulations permit other contracting procedures when it is determined to be in the best interest of the government.[2]

Examples of other procurement procedures used in

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[1] ASPR REG. 3 TITLE 10, U.S.C. 2202 18-102, P. 18: 2 (1974).

[2] *Ibid.*, p. 3:1.

the past have included negotiations when competition was not available, cost plus fixed fee and cost plus award fee when the scope of construction is not known or when it is desired to have the government assume responsibility for certain unknown conditions that might otherwise preclude contractors from bidding or cause them to include amounts for contingencies that might make construction impractical. Two other types of procurement procedures that are occasionally used are the two step procurement and turnkey process. In the former the prospective contractor does his own design work based on government furnished criteria. After evaluation of the competing proposals by the military either a firm price is negotiated with a contractor chosen in the first phase or those contractors with satisfactory proposals are requested to submit a fixed price bid. The second type is the turnkey concept where one firm is responsible for both design and construction. In the most common form of turnkey construction an owner selects a firm for a project based on its experience, reputation or some other criteria and through negotiations the owner and contractor reach agreement on the form and scope of the contract including price. An alternate form of turnkey is one in which there is competition among firms interested in a project and the award is made based on an evaluation of the proposals with the successful firm then awarded a contract for construction. This concept is frequently used by the aircraft companies

and the Department of Defense in the procurement of new types of military aircraft. In this case all proposers are paid for submitting a proposal to defray the multi-million dollar expenses involved in developing the designs included in the Proposals.[3] In recent years the turnkey concept with award based on an evaluation of the proposal rather than negotiations has also been used for the construction of military family housing but without the provision for paying for the proposals. That is, the only proposer that is paid is the one awarded the contract for construction and his costs for developing the proposal are included in the construction award amounts.

The most common complaint against competitive bidding for housing based on completed plans and specifications is that the design does not take full advantage of the expertise that contractors regularly building for the civilian housing market possess. The two step contracting procedure attempts to gain this expertise with the contractor submitting his own design proposal based on broad design criteria, essentially the Housing and Urban Development (HUD) minimum property standards with some minor restrictions/criteria established by the military. The first step consists of a request for proposals from interested contractors and an evaluation as to suitability

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[3] ASPR REG. 1 TITLE 10, U.S.C. 2202 3-211, P. 3-211, p. 3:10 (1974).

and compliance with the design criteria. At the completion of this first phase the contractors with the most promising proposals are requested to submit a complete proposal including price. Since all proposals received under the second phase were previously screened for technical adequacy, award is generally made on the basis of low price rather than obtaining the best house for the available funds.

The Navy developed the turnkey concept for housing procurement to permit the award for construction to be based on the quality of design rather than the low bid. This procedure is intended to make maximum use of the design and construction expertise of developers regularly engaged in the construction of private housing developments. This type of procurement is defined as competitive negotiations under the ASPR.

The procedure includes providing the prospective proposer with the design criteria, again essentially HUD minimum property standards; the amount of funds available for construction and the criteria used to evaluate the various proposals. In essence, each proposer then attempts to provide the best house and housing development possible within the fund limitation and using the evaluation and design criteria provided. It is this contractual procedure and the challenge it presents to builders that concerns this thesis. To provide specific details regarding the Navy turnkey housing concept, a recent request for

proposals for an actual project has been used as a basis for study rather than general specifications and a standard evaluation guide. The request for proposals used was N62474-75-R-6010 dated 30 December 1974 for 500 family housing units in Murphy Canyon for the Naval Complex, San Diego, California. The project is a portion of a long-range housing development in the area, but it is a complete and independent project.

The Navy is the predominant user of the turnkey concept for family housing among the military services and the request for proposals used as a basis for this paper is the most current form of the request. The Air Force has used the turnkey concept to procure family housing at Lowry Air Force Base in Denver but it was not used as the basis of this study because it was the first experience the Air Force had with the concept. The personnel involved in the Lowry project felt that due to their lack of experience with managing turnkey construction it was not a typical turnkey project and recommended the Navy procedures as more representative of the state of the art.[4]

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[4]Private communication with Rod Gambrell, Housing Construction Administrator, DCE, USAF Shepard Air Force Base, Texas, January 14, 1975.

CHAPTER II

THE CONTRACTOR'S POSITION

Under the competitive contract all bidders are estimating from the same plans and specifications and with the knowledge that award will be made to the contractor with the low bid. The contractors' main problems during the bidding process are involved in determining the lowest material prices and estimating the man hours required for construction, usually straightforward tasks. The major decisions generally involve establishing overhead and profit percentages to apply to the direct and indirect costs.

Since the turnkey concept requires the contractor to be both designer and builder, the decision process becomes more involved than it is for competitive bidding. However, since much of the civilian housing is built by housing developers who both design and build, albeit perhaps with subcontracting major portions of the work, it is not an entirely unfamiliar situation. The developer in the civilian market is often competing with other developers, not for the right to build a project but to have his units sell or rent in the face of competition. To improve his chances of success, he can conduct market surveys to determine the preferences of the clientele he

desires to attract and may take considerable time in reaching decisions without affecting his chances for success. Even without any of this he may still be successful if demand simply exceeds supply.

Under the Navy turnkey concept, proposers are operating under somewhat different guidelines than normally associated with housing developments and these do impact on the proposer's chances of success. Specific areas include the following.

A. Duration of time to prepare proposals is limited. Sixty-four calendar days were allowed for the 500-unit project considered.

B. Statutory limitations regarding the maximum amount spent on any one unit must be complied with. This upper limit is $40,500 including a prorated share of site development costs.

C. Statutory size limitations regarding the minimum and maximum allowable square footage per unit must be complied with. These square footages vary in increments with the pay grade of the military member the project is designed to house. The senior personnel rate more square footage per unit than junior personnel.

D. The evaluation criteria coupled with design criteria may dictate the construction of units with significantly different features than those that have proven to be required for a

project to be commercially successful. Two examples of commercial features not accepted by the Navy are the community swimming pool and carpeting on the floors.

The prospective proposer is therefore faced with the problem of coming up with both a site development plan and the design of individual units within a short period of time that will satisfy a new set of cost and size restrictions. In addition, the design must include features not necessarily selected to attract a certain segment of the home buying public but to impress an evaluation board of professional engineers and architects not normally involved in the housing field. The evaluation guide provided in the request for proposals does not significantly aid in the solution of the problems since it does not provide the relative weights of the various features.

Other than the general statement about the relative order of the major features contained in the evaluation guide the importance of specific features and the points for individual features are not public knowledge. There have been efforts made by individual contractors to obtain additional information about the evaluation procedure used by the Navy citing the "truth in negotiations" clauses in the ASPR as the basis for these appeals but

these have been rejected.[5]

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[5]Private communication with Yates P. Boswell, Family Housing Specialist, Naval Facilities Engineering Command, Washington, D. C., November 1, 1974.

CHAPTER III

AN APPROACH TO THE PROBLEM

The problem is to select a slate of features to incorporate in the design of the homes that will maximize the probability of award while staying within the cost constraint. While developers regularly analyze the advantages of various features in the design of private housing, the decision generally depends on whether or not it will help sell the house to the buying public.

In turnkey housing the evaluation is done by professional engineers and architects who will presumably put more emphasis on design and engineering features that increase the livability and maintainability of both the individual dwelling unit and the community as a whole over a long period of time. This necessitates the development of a scoring system to aid in evaluating each individual feature. The scoring system must balance the weight given to those features and amenities that make private housing developments attractive to the house buying public and the engineering and design aspects that professional engineers and architects are concerned with. Since the scoring system is intended to equalize the weight given to the two differing needs, it should be expected that the resulting mix of features will

contain less amenities than civilian housing in the same price range but some upgraded engineering features.

One method of determining the mix of features would be an iterative process of designing with a set of features, estimating the cost and adding or dropping features to either satisfy the cost constraint or increase the evaluation score. This is not a practical solution since time to prepare the proposal is limited and it involves a substantial expenditure of design funds with limited chance of return. The Navy historically estimates that the cost of finished design will be about six per cent of the construction cost and a preliminary estimate and design, which approximates the proposal submittal, will cost between one and two per cent of the construction cost.[6] Since a housing development usually contains only a few different structures constructed repetitively, the design cost is usually less than this percentage. Assuming the one per cent figure for developing a proposal, it would result in a cost of $141,250 for the San Diego Project. According to the Navy Resident Officer in Charge of Construction at San Diego, the proposers estimated they spent between $40,000 and $50,000

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[6]ASPR REG. 3 TITLE 10, U.S.C. 2202 18-306.2, p. 18:13.

developing proposals.[7]

A more efficient method for determining the mix of features is to define each feature and its associated evaluation score and cost in sufficient detail to permit a mathematical solution that maximizes the evaluation score while staying within the cost constraint. Relying on a mathematical model requires the development of underlying assumptions and the results evaluated in light of the assumptions.

The assumptions underlying the proposed solution are as follows:

A. An analysis of the design features commonly included in private housing developments in the same general geographical area and price range as the proposed military project correlate to the features desired by the evaluation board. If this were not true, there is no rationale for using turnkey since it would indicate the military desires housing substantially different from civilian housing and this would only be obtained by a military design contract.

B. The military has some firm ideas on certain design features and engineering aspects that must be incorporated in the design. These

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[7]Private conversation with Commander Allen P. Boothe, CEC, USN, Resident Officer in Charge of Construction, Western Division, Naval Facilities Engineering Command, San Diego, California, June 4, 1975.

are spelled out in the specification portion of the request for proposals and takes several forms, including the specific exclusion of materials permitted by the HUD criteria such as wood shake or wood shingle roofs; the specific inclusion of certain features such as kitchen exhausts vented to the outside and the modification of HUD criteria such as specifying minimum room dimensions rather than minimum room size in square footage.

C. The military will put more importance on engineering and specification aspects of the design than the home buying public. This is implicit in the composition of the evaluation board.

D. There are certain areas of the design and engineering phase of the proposal that are not directly related to cost. Certain features that are desired and will aid in evaluation will not necessarily increase project cost. Examples of this include the placement of units to provide clustering of units to provide open space, variation of structure appearance and preservation of natural features.

E. It is assumed that a proposer has an architect and engineering team capable of designing the project to maximize the "no cost" features,

such as utility and site work. In 1970 the author worked in quantity takeoff and estimating for a site work and utility contractor who was asked to furnish a quote for all site work and utilities (all work outside the five foot line from each dwelling) for a development of 300 housing units for the Air Force at Wright Petterson Air Force Base. The project was being procured under the two step contracting procedure and four of the five contractors involved in the second step requested a quote based on their set of plans. Each set included the same basic design features, curvilinear streets, sidewalks, landscaping, etc. and presumably each would have generated about the same number of points if evaluated, however, the range in efficiency in design, basically length of roadways and utility runs resulted in a range of quotes from about $1,000,000 to over $2,000,000. Since cost is not the determining factor, efficient design of standard features is necessary to make funds available for additional "cost" features.

F. The contractor either has or can estimate the cost of each possible feature on a unit basis such that the sum of the parts is equal to the whole. Since the approach includes

consideration of all the cost evaluation features to obtain the maximum evaluation score while satisfying the cost constraint, it is essential to have identifiable cost data which may be added to achieve a total price.

The proposed solution consists of developing a scoring system for each feature and adding the features to obtain the maximum score while staying within the cost constraint and satisfying the design criteria.

CHAPTER IV

SCORING AND THE LINEAR PROGRAM

The problem of assigning a value for each possible feature that approximates the Navy's scoring system is difficult; however, a scoring procedure can be developed that will lead to the assignment of a numerical value to each evaluation feature. This procedure is based on a scoring model developed by Dean and Nishry for evaluating and selecting engineering projects.[3] A review of operations research journals did not yield any more recent scoring models which address the scoring problem as directly. A unique feature of the Dean and Nishry model is the incorporation of the knowledge and experience of the engineering and construction personnel in determining factors, weights and values.

The methodology used to determine a feature's value can be summarized in the flow diagram of Figure 1 and is explained in detail as follows:

A. Review the evaluation manual portion of the request for proposals to determine cost and

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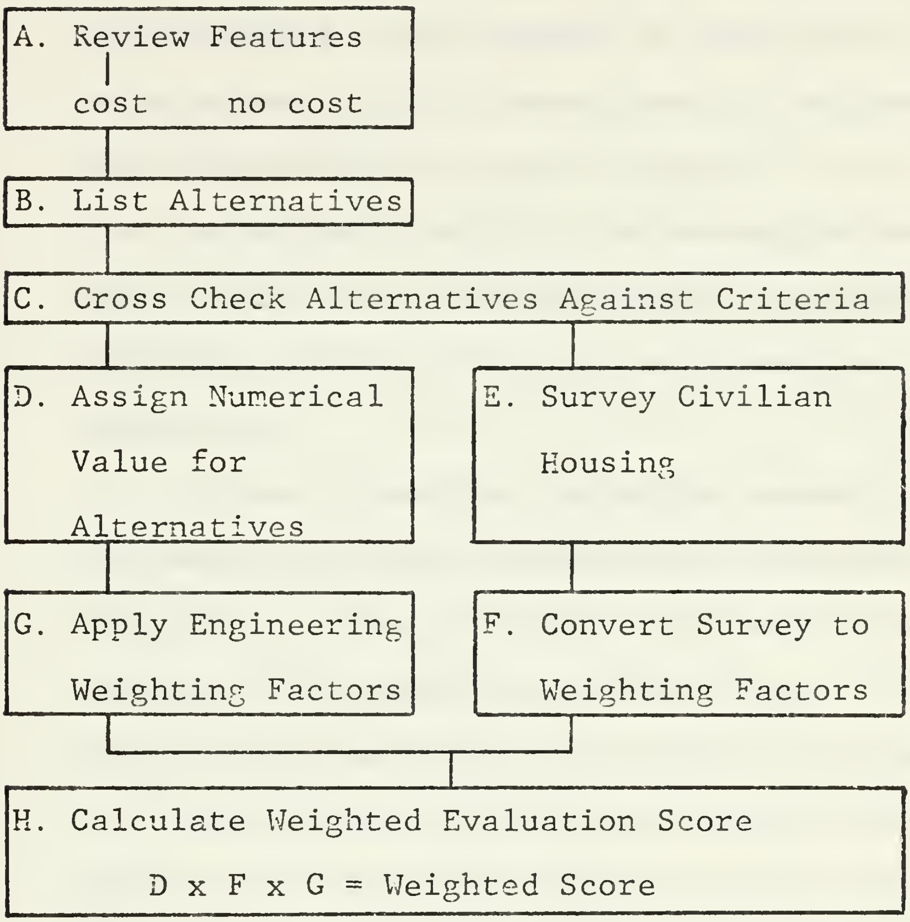
[3] Burton V. Dean and Meir J. Nishry, "Scoring and Profitability Models for Evaluating and Selecting Engineering Projects," Operations Research, 13 No. 4 (Jul.-Aug., 1965), pp. 550-569.

FIGURE 1

DEVELOPMENT OF THE SCORING SYSTEM



no cost features.

A condensation of the evaluation manual for the San Diego Project studied is included as Appendix A. Each aspect of design and construction in this manual must be reviewed and a determination made to whether it is a cost or no cost feature. The determinations used in this paper are included in Appendix B.

B. Subdivide each cost feature into possible alternates.

In many cases the evaluation manual includes the logical subdivision of features into alternatives; in other instances it can be based on a knowledge of construction.

C. Cross check the design and evaluation criteria.

The list of cost features must be checked against the latest HUD minimum property standards and the design/construction criteria portion of the request for proposals. Since the evaluation manual and HUD standards are generalized to cover the entire country, there probably will not be conflicts with the HUD criteria. The design/construction criteria is generally more restrictive than the HUD criteria since it is for a specific project in a specific location and frequently results in eliminating alternatives from further

consideration. Examples given in the previous chapter included wood shake roofs and exhaust fans.

D. Review the alternatives within an evaluation feature and assign a numerical value to each alternative.

Determining a rationale for establishing the range of these numerical values is a critical part of the scoring system. Dean recommends that the range be based on an analysis of the alternatives to determine the number of distinct values experienced personnel could assign recognizing that different alternatives could have the same value.[9] The range selected is 0 (least favorable) to 5 (most favorable) which varies from Dean's 1 to 5 range slightly. The procedure followed was to list the acceptable alternatives for each feature including the minimum acceptable in descending order of desirability. Since this will vary with the professional background of the evaluator, it is possible for different listings to result. The range of 6 worked quite well with most features having four or five alternatives and only a few with one alternative to the minimum

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[9]Dean and Nishry, p. 553.

standard. Each alternative was then assigned a numerical value from 5 through 1 to reflect its desirability over the standard which has the value zero.

E. Survey new civilian housing developments with the same general composition.

The survey should be restricted to the same geographical area as the proposed project and the developments surveyed should be aimed at approximately the same demographical group. Each cost evaluation feature should be surveyed and the results tabulated to find the mix of evaluation alternatives included in current designs.

F. Convert the survey results into weighting factors.

Dean and Nishry determined their weighting factors by using experts to rank-order the various factors in the absence of historical data.[10] Since the survey results are historical data, they can be used as weighting factors. The scale used is as follows:

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[10] Dean and Nishry, p. 555.

Percentage of Time Evaluation Alternative Occurred	Multiplication Factor
80-100	5
60-79	4
40-59	3
20-39	2
0-19	1

G. Engineering weighting factor.

The survey results are biased in favor of design over engineering features because the homes surveyed were designed for sale to private individuals not professional engineers. To shift the evaluation scores back toward the engineering aspects desired by the evaluation board, a weighting factor must be applied to the alternatives for engineering features. The following conversion scale was used.

Alternative Value	Weighting Factor for Engineering
5	1.500
4	1.375
3	1.250
2	1.125
1	1.0

H. Obtain the weighted evaluation score for each alternative.

The following equation is used:

Alternative value x survey multiplication factor x engineering weighting factor. The weighted evaluation scores are listed in Appendix E.

The problem can be put in mathematical form once the weighted evaluation scores and unit cost data are completed. The problem is assumed to be linear even though the repetitive construction of essentially similar units is non-linear due to the learning curve effect discussed by Ostwald[11] and Parker and Olgesby.[12] The linearity assumption is justified by basing the cost data not on an individual unit but the average of the entire project.

Since the problem is one of obtaining the highest possible evaluation score within linear cost and design constraints, operations research teachniques for solving linear problems may be used. The problem is one of maximization and may be put in the form:

$$\text{Maximize} \quad \sum_{j=1}^{n} C_j X_j$$

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[11] Philip F. Ostwald, Cost Estimating for Engineering and Management (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1974), p. 271.

[12] Henry W. Parker and Clarkson A. Olgesby, Methods Improvement for Construction Managers (New York: McGraw-Hill, 1972), p. 180.

Subject to $\sum_{j=1}^{n} A_{ij}X_j \leq B_i$ for i = 1,...,m

Where C_j = weighted value of alternative X_j

A_{ij} = coefficient of alternative X_j in constraint row i

B_i = constraint in row i

To this problem must be added the additional constraint that all variables take on only integer values; that is an alternative must either be included or excluded from a particular dwelling unit since functional answers are meaningless. This additional constraint complicates the solution procedure significantly. As discussed by Wagner rounding off fractional values either up or down does not necessarily yield the optimal integer solution.[13] His example illustrates the problem.[14]

The optimal non-integer solution to the problem

$$\text{Maximize } 21X_1 + 11X_2$$
$$\text{Subject to } 7X_1 + 4X_2 \leq 13$$
$$X_1, X_2 \geq 0$$

is X_1 = 1 6/7m X_2 = 0 with a maximum value of 39. The addition of an integer constraint to the same problem changes the solution set to X_1 = 0, X_2 = 3 with a maximum

[13] Harvey M. Wagner, Principles of Operations Research with Applications to Managerial Decisions (Englewood Cliffs, New Jersey: Prentice-Hall, Inc. 1969), p. 448.

[14] Ibid., p. 463.

value of 33.

The addition of the integer constraint to the maximization problem restricts the solution techniques that will solve the general problem. There are two classes of integer problems: the general problem in which a variable may take any integer value and a specialized case in which a variable is restricted to either a value of zero or one. The specialized zero-one problem may be solved by a wider range of techniques than the general case and is therefore the preferred form.[15]

The turnkey housing project may be formulated either as a zero-one problem or one with a range of integer values depending on the degree of similarity or uniformity of features required between units. The approach taken in the paper is the zero-one problem. While there is no strict requirement to include identical features in all units of the same size, it is preferred by the Navy because it eases maintenance and eliminates a possible source of friction with occupants whose units have the fewest amenities. A project that included units for several different pay grades and therefore had different square foot and dollar limitations on units with the same bedroom size might be formulated more efficiently by permitting a range of integer values.

The solution technique chosen to solve the problem

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[15] Ibid., p. 480.

$$\text{Maximize} \quad \sum_{j=1}^{n} C_j X_j$$

$$\text{Subject to} \quad \sum_{j=1}^{n} A_{ij} X_j \leq B_i \quad \text{for } i = 1, \ldots, m$$

$$\text{And} \quad X_j = 0 \text{ or } 1 \text{ for } j = 1, \ldots, m$$

utilizes the BALAS or partial (implicit) enumeration algorithm. The objective function includes the weighted evaluation score of all possible alternatives and the constraints include a long row with the costs of each alternative and shorter rows reflecting the various evaluation features and the design criteria.

CHAPTER V

THE HOUSING SURVEY AND UNIT COST DATA

The survey of the civilian housing developments follows the subdivision of the cost features into the various alternatives as discussed in Chapter IV. Since the results of this survey are a major factor in determining weighted evaluation values, a rationale must be developed for selecting projects for inclusion in the survey to minimize biasing the results.

The considerations should include the type housing desired, single, duplex, town house, etc.; the average cost per unit and the unit sizes in terms of bedrooms. A rationale can be made for restricting the survey to rental apartments since the Navy acts as a landlord providing housing including all utilities, public services and maintenance but excluding telephone for a fixed monthly rate. This monthly rate is the service members' pay allowance for quarters and depends solely on pay grade, not the size or features of the unit. The survey has not included rental units, however, for several reasons. While both the Navy and civilian landlord are concerned with the maintainability of a project, the developer of rental units is primarily concerned with attracting occupants at a rental rate that yields a profit

while the Navy is not concerned with profits and is not directly competing for occupants. In addition, the majority of apartments are designed for unmarried personnel, young couples with few, if any children, or older couples with no children at home. As a result most apartment developments have predominately two or less bedrooms per unit and little in the way of recreation facilities for school age children. In contrast, military family housing is nearly always built for families with several children with nearly an even split between three and four bedroom units.

The survey initially was restricted to town house units for sale with a price between $25,000 and $35,000 to approximate the housing specified for the San Diego Project. Each unit had a street level entrance and several living levels. All shared some common walls with other units but were not directly above or below another living unit. After surveying several town house developments, it became apparent that the target population for the town houses surveyed was not the same as the military housing project. In general, the town houses were designed to attract young families with no more than two children of preschool age or older couples without children. Sales personnel at the developments explained that the extra bedrooms in the three and four bedroom units were envisioned as being used for guest rooms, sewing rooms or dens. This was evident in both the

overall size, which was less than that required by the Navy and the small size of individual rooms. For example, the four bedroom units at Madison Hill had a dining room approximately eight feet square, scarcely large enough for a table for four when the Navy would expect a family of at least five in a four bedroom unit.

Since the floor plans used for the town house projects would not be acceptable for the turnkey project, some single family dwelling unit developments were included in the survey in an attempt to obtain floor plans that would fit the square foot criteria and be designed for the same market population as the military housing project.

Initially the survey was limited to those features included in the base price of the unit surveyed. Since the majority of the units sold included some options the survey was modified to include the most popular options. This generally included fireplaces, upgraded flooring materials, an extra bath or finished family room.

The finished survey, the results of which are listed in Appendix D, included four town house developments, five single family developments and one patio home project. The latter is a concept that combines the common land features associated with town house developments with the privacy of a single family house. This is done by placing the home on one corner of a lot typically 40 foot by 60 foot and placing neighboring homes and fences such

that the lot is walled in and provides a private back and side yard. All other land including that in front of homes is common land and maintained by the developer.

During the survey several of the evaluation item alternatives were modified to more closely reflect the combinations of materials found in use. Those included interior doors and insulation material thickness.

Certain items required by the specifications were neither standard or an option on any of the units surveyed. This occurred with kitchen exhaust fans where the alternatives were a range hood with exhaust fan or an exhaust fan, both vented to the outside. All units surveyed had range hoods vented into the kitchen work area which is permissible under HUD criteria.[16] A survey factor weight of one was used for alternatives with a percentage of occurrence of zero. The weighted values of the evaluation alternatives are listed in Appendix E.

The cost estimating procedure used for this thesis differs from the construction industry practice to simplify the example. The price of each alternative for the various evaluation features was obtained from "Means Cost

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[16] HUD minimum property standards for one and two family dwellings, REG. 4900.1, Vol. 1, 615-2.3, p. 6-15-3 (1973).

Data."[17] The price of the minimum design alternative was subtracted from each of the more desirable alternatives to find the price difference. It is these price differences that are used in the cost constraint and listed in Appendix C. In practice a contractor in the housing field with an accurate cost accounting system would have a large bank of cost data to use in determining price differences. A detailed estimate of material and labor would be required only for those alternatives not previously built or bid on.

The request for proposals includes the amount programmed for award. For the San Diego Project this is $14,125,000 for 500 units.[18] Several steps are involved in converting this amount into the dollar amount for the cost constraint and are described below. The steps utilizing the city cost index can be eliminated if the cost data is from the same geographical area as the new project.

1. Convert the amount for contract award into standard dollars. The city cost index for San Diego in Means Cost Data is 105. This reduces the amount for award to $13,452,381

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[17] Robert S. Means, Building Construction Cost Data 1974, Ed. Robert S. Godfrey (32nd ed.; Duxbury, Massachusetts: Robert Snow Means Company, Inc., 1974).

[18] Department of the Navy, Naval Facilities Engineering Command, Request for Proposals No. NG2474-75-R-6010, December 30, 1974, p. IC-2.

standard dollars.

2. Calculate the cost of constructing the approximate mix of units using the minimum standard features. The basic square foot size for the 3 and 4 bedroom units is 1200 and 1350 SF respectively, with 250 units of each. This equates to 637,000 SF in the project. Using Means Data for public housing projects and assuming the minimum standard would be about the 1/4 percentile, a price/SF of $17.45 is applicable. This includes building and site work, overhead, and profit but not land costs. Since the government provides the land for this project, there is no adjustment required for land costs. The $17.45/SF yields a price of $11,124,375 for construction.
3. Calculate the cost of design. The amount for award must be reduced by the estimated design cost to find the amount available for construction. Because of the repetitive use of the building design in a housing development, the design fee for multi unit housing is generally less than six per cent; however, assuming a four per cent fee reduces the amount for construction to $12,934,932.
4. Calculate the amount available for evaluation features. This is the difference between the

$12,934,982 for construction and the $11,124,375 for development meeting the minimum standards or $1,810,607.

5. Convert the total available for evaluation features into an amount per dwelling unit. This is necessary to maintain uniformity with the unit price data used to simplify formulation of the problem. This results in an allowance per unit of $3,621.21.

The cost per square foot of the surveyed units must exceed the program cost per square foot of the proposed units to insure the survey results indicate more desirable alternatives than it is possible to obtain. The average cost of surveyed units after adjustment for land costs was $26.72 compared to the program amount of $21.10 and minimum standard of $17.45.

CHAPTER VI

TESTING THE MODEL

The problem formulation discussion in Chapter IV listed the two cases of a range of integer values and the zero-one restricted form. The University of Colorado Computing Center Library contains three integer programs, two that are restricted to zero-one formulations and one that can solve either zero-one formulations or range of integer value problems. The latter program, titled ARRIBA, was selected for use with the model because of the increased flexibility it provides in problem formulation.[19] A detailed discussion on the use of this program is contained in Appendix F. While the program is dimensioned for a matrix of 100 rows by 100 columns including the objective function row and constraint column, it is restricted to solving problems that in formulation are about 50 rows by 100 columns.

To conserve columns in formulating the problem, the differences between three and four bedroom units was handled in the calculation of unit cost data. That is, the cost data used were the average of the cost of an

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[19] R. E. Woolsey, Brady Holcolm and Peter Ryan, <u>ARRIBA, an All-Integer Programming System, Preliminary User Information Manual</u> (Control Data Corp., 1969), p. 4.

alternative for a three bedroom unit and a four bedroom unit. This procedure reduced the number of variables by about a hundred, down to the 205 various alternatives. The row formulation generally followed the division of features with the constraint that the solution must have exactly one alternative for each possible feature. In addition to the objective function and cost constraint which include all the variables, there are a few linking constraints to reflect the interrelationship of several of the features. Examples of these constraints are the relationship of the flooring system to the foundation system and location of a utility room in the basement with the foundation system.

The problem size in practice might vary somewhat from the 50 rows, 206 columns used in the example due to differences in establishing alternatives and formulating constraints, but it is representative of the size and shape of the problem. It is recognized that the size of the problem precludes solving it as an entity at this time; however, it is felt that segmenting the problem can yield meaningful, if not optimum, results provided judgment is used in dividing the problem into segments.

The cost constraint for evaluating the model was obtained by using the calculated unit cost data and the survey results to obtain a calculated average cost per feature. The sum of these costs, $5,696,188, represents the amount spent on alternatives for the average survey

house. If the entire problem was solved with this amount as the cost constraint, there should be a correlation between the solution and the survey results. The degree of correlation should provide a measure of the weighting factors used. If the weighting factors are accurate, the solution set for design factors should indicate alternatives slightly lower than the survey results while the engineering factors should be slightly higher.

Since the problem size exceeds the program capability, a set of ten features, including four design and six engineering features, was chosen for the model. The items chosen dealt with living accommodations, kitchens and bathrooms. The cost constraint was found by summing the unit cost-survey result averages for the selected features. The resulting size of the model problem was 12 rows by 51 columns.

CHAPTER VII

INTERPRETING THE RESULTS AND SENSITIVITY ANALYSIS

The model problem comprised of ten features with a total of fifty variables was first run with a computer time limit of T = 7. When it failed to yield a solution due to insufficient time the limit was increased to T = 200, chosen to correspond to a maximum cost per run of approximately $100. When the computer again failed to reach a solution due to insufficient time the size of the problem was reduced to 45 variables by eliminating the kitchen sink as a feature being evaluated. The cost constraint was reduced by the average cost of this feature from the survey results.

The resulting problem consisting of nine features, three dwelling unit design and six dwelling unit engineering, included 45 variables and 10 constraint rows. This problem was small enough to be run within the time limit and yielded an optimal solution, that is the program ran to completion. As discussed in Appendix F the print out column for the objective function minimizes the sum of the variables not in the basic solution. The variables with the value of zero are those in the solution set and the true objective value is obtained by summing the

coefficients of these variables.

Sensitivity testing was performed by varying the cost constraint. The initial plan was to test the model with the cost reduced by 20 per cent and then increased by 20 per cent and comparing the results of these three runs with each other and with the survey results.

Changing the cost constraint affects the operation of the program by changing the number of feasible solutions in the same direction as the change in cost constraint. The plus 20 per cent problem terminated because of time before reaching optimality and had to be rerun with more time allowed to obtain the optimum solution.

The results of the survey and the model are shown in Tables 1 and 2. A comparison between the results of the survey and the average cost run shows some correlation with the major variation in the size of the bathrooms. The model indicated the lowest scoring alternative at a savings of $308 which was then used to upgrade four of the engineering features. This shift in emphasis is in accordance with weighting given to engineering features.

Two features cannot be compared because the survey results indicated an alternative not acceptable under design criteria. These are the floor covering for the living areas and the kitchen exhaust fan. Some allowances should be made for this, possibly by converting the survey results to the acceptable alternative nearest the unacceptable alternative in cost.

TABLE 1

SUMMARY OF MODEL AND SURVEY RESULTS

DWELLING UNIT DESIGN FACTORS

	Solution Variable	Problem Variable	Weighted Score	Unit Cost in Dollars	Survey Average	Solution with -20% Cost	Solution with Average Cost	Solution with +20% Cost
Fireplace & Bookcase	1	72	6.0	825				
Fireplace	2	73	21.0	750	x	x	x	x
Freestanding Fireplace & Bookcase	3	74	4.0	425				
Freestanding Fireplace	4	75	3.0	350				
Bookcase	5	76	2.0	75				
None	6	77	1.0	0				
Oversize & Additional Bath	7	84	16.0	858				
Additional Bath	8	85	13.0	600				x
Oversize Bath & Extras	9	86	4.0	308	x			
Oversize Bath	10	87	3.0	258				
Std Size & Number	11	88	1.0	0		x	x	
Large Kitchen & 12 SF Extra Cabinet	12	89	11.0	584				
Large Kitchen & 6 SF Extra Cabinet	13	90	5.0	464				
Oversize Kitchen	14	91	4.0	344				
6 SF Extra Cabinet	15	92	3.0	120	x			
3 SF Extra Cabinet	16	93	2.0	60			x	
Standard Size Kitchen	17	94	1.0	0		x		x

TABLE 2

SUMMARY OF MODEL AND SURVEY RESULTS

DWELLING UNIT ENGINEERING FACTORS

	Solution Variable	Problem Variable	Weighted Score	Unit Cost in Dollars	Survey Average	Solution with -20% Cost	Solution with Average Cost	Solution with + 20% Cost
Hardwood floor in living area	18	107	8.5	2035				
Thick sheet vinyl in living area	19	108	6.5	885				
Std sheet vinyl in living area	20	109	4.75	713				
Vinyl tile in living area	21	110	3.25	483				
Thick vinyl asbestos tile	22	111	2.0	115			x	
Std vinyl asbestos tile	23	112	1.0	0	x	x		x
Kitchen								
Sheet vinyl over 1/8"	24	172	8.5	30				
Sheet vinyl 1/16" 1/8"	25	173	12.0	19		x	x	x
Vinyl tile over 1/16"	26	174	3.25	16				
Sheet vinyl 1/16"	27	175	5.0	8	x			
Vinyl tile 1/16"	28	176	1.0	0				
Cabinets and Counters								
Good Grade/Ceramic Tile	29	177	8.5	131				
Std Grade/Ceramic Tile	30	178	6.5	60				
Good Grade/Upgrade Formica	31	179	12.25	84	x	x	x	x
Std Grade/Upgrade Formica	32	180	2.0	13				
Std Grade/Std Formica	33	181	1.0	0				
Range hood, exterior exhaust	34	182	4.75	60		x	x	x
Exhaust fan	35	183	1.0	0	x			

TABLE 2 (CONTINUED)

	Solution Variable	Problem Variable	Weighted Score	Unit Cost in Dollars	Survey Average	Solution with -20% Cost	Solution with Average Cost	Solution with + 20% Cost
Bathroom								
Terrazzo Floor	36	190	8.5	131			x	
Ceramic Tile Floor	37	191	4.75	82				
Sheet Vinyl Floor	38	192	6.0	22	x	x		x
Vinyl Tile Floor	39	193	1.0	0				
Fiber Tub Encl, 2 Vanity, Lrg Sink	40	194	16.0	263		x	x	x
2 Vanity, Lrg Sink & Counter	41	195	6.5	218				
2 Vanity, Lrg Counter	42	196	8.5	203	x			
2 Vanity	43	197	3.25	178				
1 Vanity	44	198	2.0	37				
Wall Hung	45	199	1.0	0				

The comparison of the model results with three different cost constraints shows the expected increase in the score of the alternatives selected. Increasing the cost constraint by 20 per cent had a significant impact on the results, adding an additional bath and selecting lower ranking alternatives for three other features.

This trade off aspect should be expected and is typical of the linear optimization process where the optimum solution may change significantly with the change in a single constraint.

As mentioned earlier the number of iterations performed, and hence cost, increases with the number of feasible solutions. This is illustrated by the following results.

Cost Constraint	Iterations Required	Objective Cost	Objective Value	Program Cost
1227.166	18,085	1198.00	75.00	36.62
1533.895	34,186	1482.00	79.50	67.79
1840.674	51,138	1798.00	87.00	99.53

It should be remembered that the model included only approximately one-fouth of the total variables and the number of possible iterations is 2 to the power of the number of variables.

CHAPTER VIII

ANALYSIS AND COMMENT

The subdivisions in the evaluation manual on dwelling unit engineering and specifications make it difficult to apply a weighting factor. While the subdivisions in the other three sections facilitate the evaluation of the trade offs being made between evaluation items in each section, the range of the dwelling unit engineering factors makes this comparison difficult. As an example the evaluation items for the design of the dwelling unit generally deal with space allocation and amenities. On the other hand, the engineering items for the unit range in scope from basic structural aspects including foundation and roof design to the quality of the closet doors and kitchen sinks, relatively minor items when compared to the structural aspects. This might be alleviated by the Navy establishing a fifth division dealing with finishes, limiting the engineering division to engineering aspects and assigning the division on finishes a relative ranking among the present four divisions.

One of the justifications for the turnkey approach is to utilize the expertise of professional developers and the use of the HUD criteria facilitates this. However, the design modifications established by the Navy

preclude the use of most standard designs. This is due primarily to the Navy practice of establishing minimum room dimensions when the HUD criteria is in terms of square feet, generally larger than the square of the Navy's minimum dimension, and minimum dimensions smaller than the Navy criteria. While all ten developments surveyed satisfied the HUD criteria, the bedrooms in only three developments met the Navy criteria and only one of those had a dining room that met criteria. The floor plan for that unit was unacceptable because the net square footage exceeded the maximum allowable.

In view of the Navy's obligation to the taxpayers to obtain durable housing some variations from the HUD criteria may be justified; however, these should be clearly to improve durability and not preclude the use of commercially successful designs. Elimination by the Navy of restrictive design criteria to permit the use of standard designs should lower proposal development costs and encourage the submittal of proposals by a larger number of developers.

Research for this paper did not include the background on the development of the scoring system by the Navy. This was not considered germane since the contractor's problem is to work from the information included in the request for proposals. It is doubtful however that the operations research techniques discussed in this paper were utilized in the development of the Navy evaluation

scoring system.

Based on the experience with the model in this paper, it is believed that the Navy personnel responsible for developing the scoring system could utilize maximization techniques to evaluate the scoring system and modify it as necessary to obtain better housing within the cost constraints. The integer scoring model facilitates the comparison of score value per alternative to unit cost data. The cost data used should be that furnished with the preliminary engineering submittal developed for submittal to Congress as justification for the project. Solving a problem with these cost data and the standard evaluation scores would indicate the features that would be included in the optimum design. If this mix were not what the Navy desired in terms of durability and maintainability, the scores for particular alternatives could be varied until the desired mix were obtained. Use of this modified scoring system should improve the chances of obtaining a design with the desired compromise on design and engineering features because it is based on the program funds for the particular project being evaluated.

CHAPTER IX

CONCLUSIONS

The problem consisted of developing a model to aid private developers in determining the mix of features to include in the design of a turnkey housing project for the Navy. The design criteria is essentially the HUD minimum property standards with some modifications included in the request for proposals. The evaluation manual provided developers lists the items to be evaluated but not their respective weights. The evaluation features must be subdivided into acceptable alternatives and a value assigned each alternative. A scale of 0 to 6 was used for this. Since a goal of the turnkey concept is to obtain the expertise of the private developer a survey was made of new, private housing developments of generally similar composition to determine the alternatives built commercially. These results were converted into a weighting scale of from 1 to 5 and applied to the alternative values. The last part of the scoring system consisted of a weighting factor in favor of engineering factors over design factors. This was applied to equalize the bias in the survey resulting from surveying housing designed to appeal to non-engineers and the composition of the evaluation board who are all engineers or architects.

A unit price for each alternative was calculated from standard unit cost data and an integer linear programming model constructed. This model was designed to maximize the evaluation score while satisfying a cost constraint for the project and a constraint that one alternative for each feature must be in the solution set.

The integer program "ARRIBA" was selected for solving the model because of its flexibility to solve problems by different algorithms.[1] The program is limited however to a problem with approximately 50 rows and 100 columns and the model has 50 rows and 206 columns. A section of this model with 11 rows and 46 columns was chosen to test the scoring system and to compare the results with the survey. Sensitivity testing was done by varying the cost constraint to evaluate the variables entering the basis.

The results of the test generally correlated to the survey results however the scoring system appeared to be a little too heavily weighted in favor of engineering features over design features. It is recommended that additional sensitivity analysis be performed on the various aspects of the scoring system.

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[1] R. E. Woolsey, Brady Holcolm and Peter Ryan, Arriba An All-integer Programming System (Control Data Corporation, 1969).

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APPENDICES

APPENDIX A

CONDENSATION OF THE NAVY'S TECHNICAL EVALUATION MANUAL FOR TURNKEY HOUSING

This appendix is a condensation of the technical evaluation section of the San Diego turnkey housing request for proposals. While referred to in the project specifications as an evaluation manual, the evaluation criteria can be modified by the engineering field division requesting the proposal. The major areas of evaluation have been established by the Department and Defense and in order of decreasing importance are as follows:

(1) Dwelling Unit Design

(2) Dwelling Unit Engineering and Specifications

(3) Site Design

(4) Site Engineering

I. <u>Site Design</u>

This section includes overall planning layout, design and development of the housing site, exclusive of utility systems. It includes community appearance, compatibility of grounds and buildings, functionality, dignity and livability.

A. <u>Site Utilization and Development</u>

Includes street and block pattern, clustering of units, variation of structure appearance, structure orientation, buffering from heavy traffic and the provision of open spaces.

B. <u>Site Integration</u>

Includes the physical flow and relationship between the site and surrounding region. Aspects include the perservation of desirable

natural features, and compatability with the surrounding environment.

C. Vehicular Circulation

Includes the relationship of primary, secondary and feeder streets with regard to access to individual units and overall traffic flow. Considerations include the usability by service vehicles such as maintenance and trash collection trucks, moving vans and emergency vehicles.

D. Parking

A minimum of two spaces must be provided per dwelling unit and will be evaluated for proximity to the unit. The parking layout should not require backing into primary streets and minimize conflicts between cars entering and leaving common use parking areas.

E. Pedestrian Circulation

The walkway system must be integrated with the street system to provide a convenient, safe pedestrian circulation system. The system should provide short, direct access from the fronts of units to other units and clusters. Parking areas should be directly connected to the structure served. Walkways should provide convenient routing to recreation areas, community buildings and tot lots, with the latter accessible without crossing primary or secondary streets. Walkways should provide convenient routing to schools or school bus stops while minimizing crossings of primary or secondary streets.

F. Landscaping

This includes all considerations of location, quantity and quality of trees, shrubs and other plantings but excludes grass and/or ground cover. It includes the aesthetic effect of site grading, placement of trees and shrubs to provide privacy or shield service

areas, decorative plantings to enhance the appearance of structures and the community. Included is the maintainability of both landscaping growth and ground cover.

G. Recreation Areas

This includes major recreation areas with a minimum dimension of 50 feet and minimum size of 10,000 square feet, playgrounds approximately 600 to 2500 sq. ft. and tot lots of about 2,000 sq. ft. At least one major recreation area must be provided for every 100 units and these may be grouped to provide large open areas for team sports. At least one playground or tot lot shall be provided for every 25 dwelling units and should include suitable quantities and types of playground equipment.

II. Site Engineering

This section includes the quality of materials and engineering aspects of operation and maintenance. Utility systems are to be evaluated up to the five foot line of housing units.

A. Electrical Distribution System

Includes evaluation of design and specifications as well as aesthetics of underground and above ground systems.

B. Water Distribution System

Includes the quality and suitability of pipes and valves as well as layout design.

C. Sanitary Sewer System

Includes the type and quality of pipe and design and layout of the system.

D. Storm Drainage System

Includes grading for surface runoff, the negative aspects of

open ditches and the layout and specification of a buried piping system.

E. Gas Distribution System

Includes layout and specification of the system.

F. Outdoor Lighting

Includes street and off-street walkway lighting and area lighting of parking and recreation areas. Considerations include the quality, spacing and intensity of lights.

G. Master TV Antenna System

Includes the performance of the system and the appearance of the antenna and distribution system.

H. Street System

Includes the quality of the base and wearing surface, gradients of slopes and effective width of the streets.

I. Parking and Driveways

Includes the quality of the base and wearing surface and the width of the driveways.

J. Walkways

Includes the quality of construction and width of walks.

K. Ground Cover, Irrigation and Soil Treatment

Includes provision of topsoil, fertilizer, grass seed or sod and provisions for watering.

L. Fire Protection

III. Dwelling Unit Design

This section deals with the planning and design of the dwelling units as opposed to the durability of the material and engineering considerations. This includes the usability of the house by people,

the relationship of the house with outdoor family activities, the aesthetics of the housing unit and the amenities associated with livability.

A. Dwelling Unit Type

Includes single or duplex units, row or townhouses and two story apartments.

B. Net Floor Area

Requires deducting points for units with less than the basic net area specified.

C. Exterior Appearance

Includes the viaul effect of roof lines, entrances, garages, and fenestration as well as the relationship of units to each other and shadow effects.

D. Outdoor/Indoor Integration

Includes the layout of facilities within the unit which enhance indoor/outdoor living such as patios, screen porches, vistas, and privacy fences.

E. Storage

Includes exterior and interior bulk storage as well as closets with consideration given to size, convenience of location and usability of shape, shelves, etc.

F. Vehicle Storage

Includes size only in terms of capacity for one or two cars. Considerations include attachment or proximity to living units of covered walkways leading to units. Consideration is given to the type of facility, garage, carport or separate group parking structure and climatic conditions. Additional storage space in garages is

included under storage.

G. Functional Arrangement

Includes the relationship between living, food handling, sleeping and bathing areas and the detailed floor plan. Room layouts are considered for furnishability, furniture movement and traffic flow. The expected family size of each unit must be considered in determining room sizes, functional layout and traffic pattern.

H. Living

Includes principal and secondary living and dining areas, that is, living room, family room, and dining area. Includes convenience elements such as light switches, TV antenna outlets and amenities such as fireplaces and built-in book cases.

I. Sleeping

Includes furnishability and size with points given for area and/or dimensions exceeding the specified minimum. Consideration given to both visual and acoustic privacy.

J. Bathing

Since the number, minimum size and required fixtures is specified in the request for proposals, this section includes the number and/or size exceeding the minimum, built-in furnishing, layout and both visual and acoustic privacy.

K. Food Handling

Includes interior layout to promote work efficiency and pedestrian and product circulation as well as amount of counter space, location and amount of shelving and closet storage, overall room size is considered with regard to its effect on efficiency.

L. Utility and Work Areas

Includes provisions for occupant furnished washer and dryer and location to other work areas. Consideration given for areas suitable for ironing and/or light hobby work and other storage facilities. The location of laundry equipment in a powder room on the first floor or anywhere on the second floor is considered undesirable.

IV. Dwelling Unit Engineering and Specifications

This section includes the evaluation of the quality of construction materials and the technical adequacy of the engineering features and product specifications.

A. Foundation System

Includes the type of foundation system, slab-on-grade, perimeter wall (crawl space) and basement as well as the quality of materials and construction details. Elements considered include slab and wall thickness, reinforcing, moisture and vapor barriers, insulation and ventilation.

B. Flooring System

Includes the type of floor system and finish flooring material for areas other than kitchen and bath. Types of systems includes slab-on-grade, reinforced concrete floors, wood frame and subfloors, steel frame-wood subfloor and steel frame-concrete subfloor. Types of finish flooring includes hardwood, vinyl, cork and vinyl asbestos.

C. Exterior Walls

Includes the type construction, reinforced concrete, masonry, steel frame and wood frame; type and quantity of insulation; type sheathing, plywood, wood boards, fiber board and gypsum; and type

finish. The latter includes the full range of commercial products covering masonry, wood, wood base, mineral and aluminum.

D. Interior Walls and Ceilings

Includes wall and ceiling construction and finish.

E. Roof System

Includes the structural and quality factors, including maintanance considerations. The roof system is defined to include framing, sheathing, roofing, flashing gutters and downspouts.

F. Windows and Window Coverings

Includes the material, quality, type and size of the windows with emphasis on durability, operability and maintainability. This includes windows, screens, storm sash, window hardware, traverse rods, curtain rods and window coverings.

G. Doors (Including Hardware)

Includes both interior and exterior doors of all types and styles. Consideration given to quality of material, hardware and durability of finishes.

H. Kitchens

Includes the features, materials, equipment and finishes being provided and the durability and maintainability of those items. This includes flooring material, cabinets, countertops, sinks, sink fixtures and exhaust fans and hoods.

I. Bathrooms

Includes the type, quality and durability of fixtures, accessories and features. This includes flooring material, wainscots, lavatory, vanity, water closet, tubs, showers, medicine cabinets, exhaust fans, heat lamp and accessories.

J. <u>Interior Plumbing System</u>

Includes the water piping system and material and the drain, waste and vent system and material.

K. <u>Interior Electrical System</u>

Includes the wiring, circuit breaker, switches and fixtures.

L. <u>Heating, Ventilation, and Air Conditioning</u>

Includes equipment, accessories and duct work.

M. <u>Patios, Service Yards, and Fencing</u>

Includes material and design of patios, service yards and fencing.

N. <u>Other Miscellaneous Features</u>

Includes fireplaces, screen porches, patio roofs, built-in features, play yard equipment and other amenities.

APPENDIX B

SUMMARY OF COST AND NO COST EVALUATION FEATURES

Paragraph			Description	Cost	No Cost
I			SITE DESIGN		
	A		Site Utilization and Development		
		1	Street and Block Pattern		x
		2	Clustering		x
		3	Variation of Structure Appearance		x
		4	Structure Orientation		x
		5	Buffering		x
		6	Open Space		x
	B		Site Integration		
		1	Preservation of Natural Features		x
		2	Compatibility with Surrounding Environment		x
	C		Vehicular Circulation		
		1	Access and Traffic Conflicts		x
		2	Service		x
	D		Parking		
		1	Quantity Provided	x	
		2	Proximity to Dwelling Units		x
		3	Layout of Parking Areas		x
	E		Pedestrian Circulation		
		1	Building, Parking and Refuse Disposal Circ.		x
		2	To Recreation Areas, Bus Stops, and Community Buildings		x
	F		Landscaping		
		1	Grading		x
		2	Screening		x
		3	Decorative Plantings	x	
		4	Maintainability		x
	G		Recreation		
		1	Major Recreation Areas	x	
		2	Playgrounds & Tot Lots	x	
II			SITE ENGINEERING		
	A		Electrical Distribution	x	
	B		Water Distribution System	x	
	C		Sanitary Sewer System	x	
	D		Storm Drainage System	x	
	E		Gas Distribution System	x	
	F		Outdoor Lighting	x	
	G		Master TV Antenna	x	
	H		Street System	x	
	I		Parking and Driveways	x	
	J		Walkways	x	
	K		Ground Cover, Irrigation and Soil Treatment	x	
	L		Fire Protection	x	

Paragraph	Description	Cost	No Cost
III	DWELLING UNIT DESIGN		
A	Dwelling Unit Type		x
B	Net Floor Area	x	
C	Exterior Appearance		x
D	Outdoor/Indoor Integration	x	
E	Storage	x	
F	Vehicle Storage	x	
G	Functional Arrangement		x
H	Living	x	
I	Sleeping	x	
J	Bathing	x	
K	Food Handling	x	
L	Utility and Work Area	x	
IV	DWELLING UNIT ENGINEERING & SPECIFICATIONS		
A	Foundation System	x	
B	Flooring System		
1	Flooring System	x	
2	Finish Flooring	x	
C	Exterior Walls		
1	Wall Construction	x	
2	Insulation	x	
3	Sheathing	x	
4	Finishes	x	
D	Interior Walls and Ceilings		
1	Wall Construction	x	
2	Ceiling Construction	x	
3	Finishes	x	
E	Roof System		
1	Framing	x	
2	Roofing and Sheathing	x	
3	Gutters/Downspouts/Flashing	x	
F	Windows and Window Coverings	x	
G	Doors		
1	Exterior	x	
2	Interior	x	
H	Kitchens		
1	Kitchen Floors	x	
2	Kitchen Cabinets and Tops	x	
3	Kitchen Exhaust	x	
4	Kitchen Sinks and Fixtures	x	
I	Bathrooms		
1	Floors and Wainscots		
2	Fixtures		
J	Interior Plumbing		
K	Interior Electrical System		
L	Heating, Ventilation and A/C		

Paragraph	Description	Cost	No Cost
M	Patios, Service Yards and Fencing		x
N	Other Miscellaneous Features		x

APPENDIX C

LISTING OF EVALUATION ALTERNATIVES AND UNIT COST DATA

Site Design--Cost Data

Paragraph		Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
I D	X_1	Parking	Garage 2 car/unit	LS	510.00	EA	510	EA	510	510
	X_2		Garage 1 car/unit		170.00		170		170	170
	X_3		Carport 2 car/unit		170.00		170		170	170
			Carport 1 car/unit		Std		-		-	-
F		Landscaping Trees or shrubs/ unit								
	X_5	11	Excellent	LS	300.00	EA	300	EA	300	300
	X_6	8	Good		150.00		150		150	150
	X_7	5	Satisfactory		Std		-		-	-
G	X_8	Recreation	One/50 units	LS	20.30	EA	20.30	EA	20.30	20.30
	X_9	Backstop, bike-	One/75 units		6.77		6.77		6.77	6.77
	X_{10}	rack, seasaw, slide, swing	One/100 units		Std					

Site Engineering--Cost Data

Paragraph	Description	Alternatives
II A	Electrical Distribution	Not Evaluated

Paragraph		Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
II B	X_{11}	Water Distribution	12" main/250' 11 YD	LF/EA	11.25/470	13/.01	150.95		150.95	150.95
	X_{12}		10" " /250' "		5.25/470	13/.01	72.95		72.95	72.95
	X_{13}		10" " /300' "		5.25/470	13/.005	70.60		70.60	70.60
	X_{14}		8" " /250' "		0/470	0/.01	4.70		4.70	4.70
	X_{15}		8" " /300' "		0/470	0/.005	2.35		2.35	2.35
	X_{16}		8" " /350' "		Std	--				
C	X_{17}	Sanitary Sewer	PVC/Gravity	LF/EA	.50/0	30/0	15.00		15.00	15.00
	X_{18}		Vitclay/Gravity		.85/0	30/0	25.50		25.50	25.50
	X_{19}		Conc/Gravity		Std	--	--		--	--
	X_{20}		PVC/Pump Sta		.50/34	30/1	49.00		49.00	49.00
	X_{21}		Vitclay/Pump Sta		.85/34	30/1	59.50		59.50	59.50
	X_{22}		Conc/Pump Sta		0/34	0/1	34.00		34.00	34.00
D	X_{23}	Storm Drainage	Catch Basin each corner	LF/EA	5.15/350	10/.024	59.90		59.90	59.90
	X_{24}		Some catch basins		5.15/350	5/.012	29.95		29.95	29.95
	X_{25}		All open runs		Std		--		--	--
E		Gas Distribution Sys	Not evaluated							
F	X_{26}	Outdoor Lighting	Max 100' Interval	EA	285.00	.075	21.375		21.375	21.375
	X_{27}		" 150' "		285.00	.025	7.125		7.125	7.125
	X_{28}		" 200' "		Std	--	--		--	--
G		Master TV Antenna	Not evaluated							

Paragraph		Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
II H	X_{31}	Street System	+4' width	SY	1.65	5.92	9.768		9.768	9.768
	X_{32}		+2' width		1.65	2.96	4.884		4.884	4.884
	X_{33}		Std width		Std	--	--		--	--
I	X_{34}	Parking & Driveways	Dbl width Conc	SY	5.60/1.85	33/33	245.85		245.85	245.85
	X_{35}		Dbl width Asphalt		3.75/1.85	33/33	184.80		184.80	184.80
	X_{36}		Single width Conc		1.85	33	61.05		61.05	61.05
	X_{37}		Min width Asphalt		Std	--	--		--	--
J	X_{38}	Walkways	All +1'	SY	4.70	8.37	41.69		41.69	41.69
	X_{39}		House +1'		"	4.44	20.87		20.87	20.87
	X_{40}		Street +1'		"	4.44	20.87		20.87	20.37
	X_{41}		Std		"	--	--		--	--
	X_{42}				--					
K	X_{43}	Ground Cover	100% sod	SY	1.00	269.00	269.00		269.00	269.00
	X_{44}		75% sod		"	201.75	201.75		201.75	201.75
	X_{45}		50% sod		"	134.50	134.50		134.50	134.50
	X_{46}		25% sod		"	67.25	67.25		67.25	67.25
	X_{47}		All seed		Std	--	--		--	--

Dwelling Unit Design--Cost Data

Paragraph	Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
III B X_{53}	Net Floor Area	Basic	SF	Std	--	--	--	--	--
X_{46}		0-2% minus		19.915	24	477.960	27	537.705	507.833
X_{49}		2-4% minus		20.322	48	975.456	54	1097.388	1036.422
X_{50}		4-6% minus		20.745	72	1493.640	81	1680.345	1586.993
X_{51}		6-8% minus		21.187	96	2033.952	108	2288.196	2161.074
X_{52}		8-10% minus		21.648	120	2597.760	135	2922.480	2760.120
D X_{54}	Indoor-Outdoor Integration	All 3	EA	981.43	EA	981.48	EA	981.48	981.48
X_{55}		Lrg Patio & Encl		870.48		870.48		870.48	870.48
X_{56}		Lrg Patio & Fence		179.84		179.84		179.84	179.84
X_{57}		Std Patio & Fence		111.00		111.00		111.00	111.00
X_{58}		Lrg Patio		69.84		69.84		69.84	69.84
X_{59}		Std Patio		--		--		--	--
E X_{60}	Storage	60-75% above min	SF	11.46	66.0	756.36	78.0	893.88	825.12
X_{61}		45-60% " "			52.8	605.09	62.4	715.10	660.10
X_{62}		30-45% " "			39.6	453.82	46.8	536.33	495.08
X_{63}		15-30% " "			26.4	302.54	31.2	357.55	330.05
X_{64}		0-15% " "			13.2	151.27	15.6	178.78	165.03
X_{65}		Minimum			Std	--	Std	--	--
F X_{66}	Vehicle Storage	2 car attch'd garage	EA	1800	1	1800		1800	1800
X_{67}		2 car detch'd garage		2000	1	2000		2000	2000
X_{68}		1 car attch'd garage		500	1	500		500	500
X_{69}		2 car carport		250	1	250		250	250
X_{70}		1 car carport		Std	1	--		--	--

Paragraph	Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
III H X_{72}	Living Accomodations	Built in F.P. & Bookcase	EA	825	1	825		825	825
X_{73}		Built in Fireplace		750	1	750		750	750
X_{74}		Freestanding F.P. & Bookcase		425	1	425		425	425
X_{75}		Freestanding F.P.		350	1	350		350	350
X_{76}		Bookcase		75	1	75		75	75
X_{77}		None		Std	--	--		--	--
I X_{78}	Bedroom size	More than 20% above minimum	SF	14.25	77.25	1100.81	97.5	1389.38	1384.04
X_{79}		16-20% above min			61.80	880.65	78.0	1111.50	996.08
X_{80}		11-15% " "			46.35	660.49	58.5	833.63	747.06
X_{81}		6-10% " "			30.90	440.33	30.0	555.75	498.04
X_{82}		1-5% " "			15.45	220.16	19.5	277.88	249.02
X_{83}		Min			Std	--	Std	--	--
J X_{84}	Bathrooms	Oversize & Additnal	EA	858.60	1	858.60	1	858.60	858.60
X_{85}		Additional Bath		600.00	1	600.00	1	600.00	600.00
X_{86}		Oversize & Extras		308.60	1	308.60	1	308.60	308.60
X_{87}		Oversize		258.60	1	258.60	1	258.60	258.60
X_{88}		Min		--	--	--	--	--	--
K X_{89}	Food Handling	Oversize & 12 SF Xtra	EA	584.80	1	584.80	1	584.80	584.80
X_{90}		Oversize & 6 SF Extra		464.80	1	464.80	1	464.80	464.80
X_{91}		Oversize		344.80	1	344.80	1	344.80	344.80
X_{92}		6 SF Extra		120.00	1	120.00	1	120.00	120.00
X_{93}		3 SF Extra		60.00	1	60.00	1	60.00	60.00
X_{94}		Min			--	--		--	--

Paragraph	Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
III L X_{95}	Utility & Work Area	Main floor, separate room w/ storage	EA	726.50	1	424.80		424.80	424.80
X_{97}		Main floor, separate room w/o storage		646.50	1	344.80		344.80	344.80
X_{98}		Basement		0	1	-301.70		-301.70	-301.70
X_{99}		Main floor encl		301.70	Std	--		--	--
		Dwelling Unit Engineering--Cost Data							
IV A X_{100}	Foundation System	Basement	EA	1000	EA	1000	EA	1130.00	1065.00
X_{101}		Crawl Space		300		300		339.00	319.50
X_{102}		Slab on Grade		Std		--		--	--
B X_{103}	Flooring System Construction	Steel Frame & Conc Slab	EA	2032.42	EA	2032.42	EA	2296.63	2164.53
X_{104}		Steel Frame & Wood Floor		104.28		104.28		117.84	111.06
X_{105}		Wood Frame & Floor		-411.59		-411.59		-465.10	-438.35
X_{106}		Slab on Grade		--		--		--	--
X_{107}	Finish Flooring	Hardwood	SF	1.77	1100	1947	1200	2124	2035.50
X_{108}		Sheet Vinyl Thk		.77		347		924	885.50
X_{109}		Sheet Vinyl Std		.62		682		744	713.00
X_{110}		Vinyl Tile		.42		462		504	483.00
X_{111}		Vinyl Abs Thk		.10		110		120	115.00
X_{112}		Vinyl Abs Std		--		--		--	--

Paragraph	Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Average
IV C	Exterior Walls								
X_{113}	Construction	Reinforced Conc	EA	3824.80		3824.80		4130.78	3977.79
X_{114}		Masonry		2659.77		2659.77		2872.55	2766.16
X_{115}		Steel Frame		237.43		237.43		256.42	246.93
X_{116}		Wood Frame		--		--		--	--
X_{117}	Insulation (Walls)	4" Fiberglass w/V.B.	SF	.133	1368	181.94	1546	205.62	193.78
X_{118}		2½" " "		.093	1368	127.22	1546	143.78	135.50
X_{119}		Vapor Barrier		--	1368	--	1546	--	--
X_{120}	Sheathing	5/8" Plywood	SF	.12	1368	164.16	1546	185.52	174.84
X_{121}		1/2" Plywood		.07		97.76		108.22	102.99
X_{122}		5/8" Fiber		.05		68.40		77.30	72.85
X_{123}		3/8" Plywood		.02		27.36		30.92	29.14
X_{124}		15/32" Fiber		Std		--		--	--
X_{125}	Finishes	All Brick/Stucco	SF	1.88	1368	2571.84	1546	2906.48	2739.16
X_{126}		1/4 Brick & 3/4 wood		.665		909.72		1028.09	968.91
X_{127}		All wood unpainted		.260		355.68		401.96	378.82
X_{128}		1/4 wood & 3/4 prefinished		.065		88.92		100.49	94.71
X_{129}		Prefinished		0		--		--	--
X_{130}		Plywood		Std		--		--	--

Paragraph	Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
IV D	Interior Walls & Ceiling								
X_{131}	Wall Construction	Reinforced Masonry	EA	1470.10		1470.10		1661.21	1565.66
X_{132}		Unreinforced Masonry		1393.30		1393.30		1574.43	1483.87
X_{133}		Metal Frame		100.50		100.50		113.57	107.03
X_{134}		Wood Frame		Std		--		--	--
X_{135}	Ceiling Const	Sheetrock, spray fin	SF	.05	1200	60.00	1350	67.50	63.75
X_{136}		Sheetrock, paint		.06		72.00		81.00	76.50
X_{137}		Accoustical tile		Std		--		--	--
X_{138}	Wall Finish	Plaster, 3 coats paint	SF	.592	3900	2308.80	4290	2539.68	2424.24
X_{139}		Plaster, 2 coats paint		.542		2113.80		2325.18	2219.49
X_{140}		Drywall, 3 coats paint, 10% paneling		.084		327.60		360.36	343.98
X_{141}		Drywall, 2 coats paint, 10% paneling		.039		152.10		167.31	159.71
X_{142}		Drywall, 2 coats paint		Std		--		--	--

Paragraph	Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
IV E	Roof System								
X_{143}	<u>Framing & Sheathing</u>	Truss 24" OC + 5/8 Ply + 10" insul	EA	385.27	EA	385.27		435.36	410.32
X_{144}		Truss 24" OC + 1/2 Ply + 10" insul		347.77		347.77		392.98	370.38
X_{145}		Truss 24" OC + 1/2 Ply + 6" insul		239.77		239.77		270.94	255.36
X_{146}		Truss 24" OC + 3/8 Ply + 6" insul		202.27		202.27		228.57	215.42
X_{147}		Truss 48" OC + 3/4 Ply + 6" insul		52.27		52.27		59.07	55.67
X_{148}		Rafter 48" OC + 3/4 Ply + 6" insul		Std		--		--	--
X_{149}	<u>Roofing</u>	Claytile or Alum. Shingle	SF	.72	720	518.40	843	606.96	562.68
X_{150}		5 Ply Built up or 350" CL "A"		.18		129.60		151.74	140.67
X_{151}		325"		.12		86.40		101.16	93.78
X_{152}		300"		.06		43.20		50.58	46.89
X_{153}		235" Class C		Std		--		--	--
X_{155}	<u>Gutters & Flashing</u>	Copper	SF	1.20	50	60.00	60	72.00	66.00
X_{156}		Lead		1.15		57.50		69.00	63.25
X_{157}		Aluminum, Galv Iron		.55		27.50		33.00	30.25
X_{158}		PVC		Std		--		--	--

Paragraph	Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
IV F X_{159}	Windows	Wood frame, insul	EA	83.00	8	664.00	9	747.00	705.50
X_{160}		Wood frame		61.00		488.00		549.00	518.50
X_{161}		Alum frame, insul		15.00		120.00		135.00	127.50
X_{162}		Alum frame		Std		--		--	--
G	Doors								
X_{163}	Exterior	Decorative, solid wood	EA	200	2	400	2	400	400
X_{164}		Birch, solid wood		100		200		200	200
X_{165}		Pine, solid wood		Std		--		--	--
X_{167}	Interior Room & Closet	Wood finish/wood finish	EA	520	EA	460		540	500.00
X_{168}		Wood finish/metal		320		260		300	280.00
X_{169}		Painted/metal		155		155		180	167.50
X_{170}		Hardboard/metal		50		50		60	55.00
X_{171}		Hardboard/fiber		Std		Std		Std	--
H	Kitchens								
X_{172}	Floor	Sheet vinyl, over 1/8"	SF	.55	56	30.80	56	30.80	30.80
X_{173}		Sheet vinyl, 1/16 1/8		.35		19.60		19.60	19.60
X_{174}		Vinyl tile over 1/16		.30		16.80		16.80	16.80
X_{175}		Sheet vinyl 1/16		.15		8.40		8.40	8.40
X_{176}		Vinyl tile 1/16		Std		--		--	--

Paragraph	Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
IV H X_{177}	Cabinets & Counters	Good grade/ceramic tile	EA	131.60	EA	131.60	EA	131.60	131.60
X_{178}		Std grade/ ceramic tile		60.50		60.50		60.50	60.50
X_{179}		Good grade/upgrade Formica		84.60		84.60		84.60	84.60
X_{180}		Std grade/upgrade Formica		13.50		13.50		13.50	13.50
X_{181}		Std grade/std Formica		Std		--		--	--
X_{182}	Exhaust Fans	Range hood, ext exh	EA	60.00	1	60.00	1	60.00	60.00
X_{183}		Exhaust fan		Std		--		--	--
X_{185}	Kitchen Sinks	Stainless Steel 42"	EA	120	EA	120	EA	120	120
X_{186}		Stainless Steel 32, 36"		105		105		105	105
X_{187}		Cast Iron 42"		72		72		72	72
X_{188}		Cast Iron 32, 36"		60		60		60	60
X_{189}		Single Bowl, Cast Iron		Std		--		--	--
I	Bathrooms								
X_{190}	Floors	Terrazzo	SF	1.75	70	122.50	80	140.00	131.25
X_{191}		Ceramic tile		1.10		77.00		88.00	82.50
X_{192}		Sheet vinyl		.30		21.00		24.00	22.50
X_{193}		Vinyl tile		Std		--		--	--

Paragraph	Description	Alternatives	Unit	Unit Cost	3 Bedroom Units	3 Bedroom Total	4 Bedroom Units	4 Bedroom Total	Unit Average
IV I X_{194}	<u>Fixtures</u>	Fiber tub encl/ 2 vanity, lrg sink	EA	263.30	EA	263.30	EA	263.30	263.30
X_{195}		2 vanity, lrg sink & counter		218.30		218.30		218.30	218.30
X_{196}		2 vanity, lrg counter		203.30		203.30		203.30	203.30
X_{197}		2 vanity		178.50		178.50		178.50	178.50
X_{198}		1 vanity		89.25		89.25		89.25	89.25
X_{199}		Wall hung		Std		--		--	--
J X_{200}	Interior Plumbing	Copper/CI	EA	429	EA	429	EA	429	429
X_{201}		Copper/PVC		Std		--		--	--
K X_{202}	Interior Electrical	CU/150 Amp	EA	107	EA	107.00	EA	107.00	107.00
X_{203}		CU/100 Amp		27		27.00		27.00	27.00
X_{204}		AL/150 Amp		80		80.00		80.00	80.00
X_{205}		AL/100 Amp		Std		--		--	--
L	HVAC	Not Evaluated							

APPENDIX D

RESULTS OF THE HOUSING SURVEY

UNITS SURVEYED

Code	Development	Developer	Location
A	Madison Hill	Perl-Mack	Sheridan Blvd. & US36
B	Arbor Green	Witkin	88th & Wadsworth
C	Woodglen Square	Wood Bros.	120th & N. Colorado Blvd.
D	Country Road	Sabra Enterprises	88th & Wadsworth
E	The Pond	Writer	88th, 3 mi. West of Wadsworth
F	Parkwood	Wood Bros.	S. Boulder Rd. & Garfield
G	Hillsborough	American Bldrs	S. Bouler Rd. & Garfield
H	East Glenn	Crown Bldrs/ National Homes	128th & Colorado Blvd.
I	Kings Mill on the Hill	Witkin	88th, 1 mi. west of Wadsworth
J	The Pond	Writer	88th, 3 mi. west of Wadsworth

Town Houses	A, B, C, D
Cluster Homes	E
Single Family Homes	F, G, H, I, J

SURVEY RESULTS

Site Design/Site Engineering				A	B	C	D	E	F	G	H	I	J	E
I D X_1	Parking	Garage 2 car/unit	4											
X_2	Large Structure,	Garage 1 car/unit	3											
X_3	Remote From Unit	Carport 2 car/unit	1											
X_4		Carport	Std	x	x	NA	NA	NA	NA	NA	NA	NA	NA	2
F X_5	Landscaping	Excellent	5			x		x						2
X_6		Good	2		x		x							2
X_7		Satisfactory	Std	x					N	O	N	E		1
G X_8	Recreation Area	One/50 units	5											
X_9	Major area (10,000	One/75 units	2		x		x							2
X_{10}	sq. ft, 50' min dia)	One/100 units	std	x		x		x	x	x	x	x	x	8
II A	Electrical Distribution	Not Evaluated												
B X_{11}	Water Distribution	12" main/250' hyd	5											
X_{12}	Main Size/Hyd Separatn	10" " /250' "	4											
X_{13}		" /300' "	3											
X_{14}		" /250' "	2											
X_{15}		" /300' "	1											
X_{16}		" /350' "	std											
		" /900' "		x	x	x	x	x	x	x	x	x	x	10

			Site Engineering			A	B	C	D	E	F	G	H	I	J	E
II	C	X_{17}	Sanitary Sewer Type Pipe/Pump Sta	PVC/Gravity	5											
		X_{18}		Vit Clay/Gravity	4	x	x	x	x	x	x	x	x	x	x	10
		X_{19}		Conc/Gravity	3											
		X_{20}		PVC/Pump Sta	2											
		X_{21}		Vit Clay/Pump Sta	1											
		X_{22}		Conc/Pump Sta	Std											
	D	X_{23}	Storm Drainage	Catch Basins Each Corner	5		x									1
		X_{24}		Some Catch Basins	3	x			x	x	x	x	x	x	x	8
		X_{25}		All Open Runs	Std			x								1
	E		Gas Distribution	Not Evaluated												
	F	X_{26}	Outdoor Lighting	Max 100' Interval	2											
		X_{27}		" 150' "	1											
		X_{28}		" 200' "	Std											
		X_{30}		" 300' "		x	x	x	x	x	x	x	x	x	x	10
	G		Master TV Antenna	Not Evaluated												
	H	X_{31}	Street System	+ 4' width	4											
		X_{32}		+ 2' width	2		x			x	x		x	x	x	6
		X_{33}		Std width	Std	x		x	x			x				4
	I	X_{34}	Parking & Driveways width/materials	Dbl Width Conc	5			x			x		x	x	x	5
		X_{35}		Dbl Width Asph	3		x			x						2
		X_{36}		Single Width Conc	1				x			x				2
		X_{37}		Min Width Asph	Std	x										1

	Site Engineering/Dwelling Unit Design			A	B	C	D	E	F	G	H	I	J	E
J X_{38}	Walkways	All + 1'	5											
X_{39}	width/material	House + 1'	4											
X_{40}		Street + 1'	3			x	x	x	x					4
X_{41}		Std	Std							x	x	x	x	4
X_{42}		All Asph		x	x									2
K X_{43}	Ground Cover	100% Sod	5		x	x	x	x						4
X_{44}		75% Sod	4	x										1
X_{45}		50% Sod	3											
X_{46}		25% Sod	2											
X_{47}		All Seed	Std											
		None							x	x	x	x	x	5
III B X_{48}	Net Floor Area	0-2% Minus	-1						x					1
X_{49}	(Deduct)	2-4% "	-2											
X_{50}		4-6% "	-3											
X_{51}		6-8% "	-4											
X_{52}		8-10% "	-5	x	x		x			x				4
X_{53}		Basic or Above	Std			x		x			x	x	x	5
D X_{54}	Indoor/Outdoor Inte-	All 3	5											
X_{55}	gration	Lrg Patio & Encl	4											
X_{56}	Patio Greater 120 SF	Lrg Patio & Fence	3			x		x						2
X_{57}	Screened Encl	Std Patio & Fence	2		x		x							2
X_{58}	Privacy Fence (30LF)	Lrg Patio	1	x									x	2
X_{59}		Std Patio	Std						x	x	x	x		4

Dwelling Unit Design				A	B	C	D	E	F	G	H	I	J	E
III E X_{60}	Storage	60–75% above min	5				x	x	x	x	x	x	x	7
X_{61}	Exterior, Interior	45–60% " "	4											
X_{62}	Bulk and Closet	30–45% " "	3			x								1
X_{63}		15–30% " "	2											
X_{64}		0–15% " "	1											
X_{65}		Minimum	Std	x	x									2
F X_{66}	Vehicle Storage	2 car attchd garage	5						x		x	x	x	4
X_{67}		2 car detchd garage	4					x						1
X_{68}		1 car attchd garage	3				x			x				2
X_{69}		2 car carport	1			x								1
X_{70}		1 car carport	Std		x									1
X_{71}		No covered parking		x										1
H X_{72}	Living Accomodations	Built-in FP & Bookcase	5											
X_{73}	Fireplace/Bookcase	Built-in FP	4		67	50	75	100	95	75	80		100	80
X_{74}	% units w/fireplace	Freestanding FP & Bookcase	3											
X_{75}		Freestanding FP	2											
X_{76}		Bookshelves	1											
X_{77}		None	Std	x								x		
I X_{78}	Bedroom Size	More than 20% above min	5		x	x	x	x	x	x	x		x	8
X_{79}	Add pts for oversize	16–20% above min	4									x		1
X_{80}	3 Bdr Min 4 Bdr	11–15% " "	3											
X_{81}	308.71 SF 389.71	6–10% " "	2	x										1
X_{82}		1–5% " "	1											
X_{83}		Min	Std											

		Dwelling Unit Design/Dwelling Unit Engineering			A	B	C	D	E	F	G	H	I	J	E
III	J X_{84}	Bathrooms	Oversize & Additional Bath	5				x	x			x			3
	X_{85}	5'x7.17' Min full size	Additional Bath	4						x	x			x	3
	X_{86}	(Main & Bedroom level	Oversize & Extras	3		x									1
	X_{87}	of tri-level counted as	Oversize	2											
	X_{88}	one story)	Min	Std											
			Less than min		x		x						x		3
	K X_{89}	Food Handling	Oversize & 12 SF extra	5					x			x		x	3
	X_{90}	Room Size	Oversize & 6 SF extra	4											
	X_{91}	Storage Space	Oversize	3											
	X_{92}		6 SF extra	2						x					1
	X_{93}		3 SF extra	1	x	x		x							3
	X_{94}		Min	Std			x				x		x		3
	L X_{95}	Utility & Work Area	Main floor, separate room w/storage	5		x		x	x						3
	X_{97}		Main floor, separate room without storage	4							x				1
	X_{98}		Basement	2						x		x	x	x	4
	X_{99}		Main Floor Encl	Std	x		x								2
IV	X_{100}	Foundation System	Basement	5					x	x	x	x	x	x	6
	X_{101}		Crawlspace	2		x	x								2
	X_{102}		Slab on Grade	Std	x			x							2
	B	Flooring System													
	X	Construction	Steel frame & conc slab	5											
	X		Steel frame & wood floor	3											
	X		Wood frame & floor	2		x	x	x	x	x	x	x	x	x	9
	X		Slab on Grade	Std	x										1

	Dwelling Unit Engineering			A	B	C	D	E	F	G	H	I	J	E
IV B X_{107}	Finish Flooring	Hardwood	5											
X_{108}		Sheet Vinyl, Thk	4											
X_{109}		Sheet Vinyl, Std	3											
X_{110}		Vinyl Tile	2											
X_{111}		Vinyl Abs, Thk	1											
X_{112}		Vinyl Abs, Std	Std								x			1
-		Carpet		x	x	x	x	x	x	x		x	x	9
C	Exterior Walls													
X_{113}	Construction	Reinforced Conc	5											
X_{114}		Masonry	4											
X_{115}		Steel Frame	3											
X_{116}		Wood Frame	Std	x	x	x	x	x	x	x	x	x	x	10
X_{117}	Insulation (walls)	4"	5		x		x	x	x					4
X_{118}		2-1/2"	3	x		x				x	x	x	x	6
X_{119}		Vapor Barrier	Std											
X_{120}	Sheathing	5/8" Plywood	5											
X_{121}		1/2" Plywood	4		x									1
X_{122}		5/8" Fiber	2				x							1
X_{123}		3/8" Plywood	1	x										1
X_{124}		1/2" Fiber	Std			x		x	x	x	x	x	x	7

			Dwelling Unit Engineering			A	B	C	D	E	F	G	H	I	J	E
IV	C		Exterior Walls (cont'd)													
		X_{125}	Finishes	All Brick/Stucco	5								x			1
		X_{126}		1/4 Brick & 3/4 Wood	4											
		X_{127}		All Wood unpainted	3				x							1
		X_{128}		1/4 Brick & 3/4 Prefin	2					x	x			x	x	4
		X_{129}		Prefinished Siding	1	x	x	x				x				4
		X_{130}		Plywood	Std											
	D		Interior Walls & Ceilings													
		X_{131}	Wall Construction	Reinforced Masonry	5											
		X_{132}		Unreinforced Masonry	4											
		X_{133}		Metal frame	2											
		X_{134}		Wood Frame	Std	x	x	x	x	x	x	x	x	x	x	10
		X_{135}	Ceiling Const	Sheetrock, Spray fin	5	x	x	x	x	x	x	x	x	x	x	10
		X_{136}		Sheetrock, Paint	3											
		X_{137}		Accoustical Tile	Std											
		X_{138}	Wall Finish	Plaster, 3 coats paint	5											
		X_{139}		Plaster, 2 coats paint	4											
		X_{140}		Drywall, 3 coats paint & 10% paneling	2											
		X_{141}		Drywall, 2 coats paint & 10% paneling	1											
		X_{142}		Drywall, 2 coats paint	Std	x	x	x	x	x	x	x	x	x	x	10

		Dwelling Unit Engineering			A	B	C	D	E	F	G	H	I	J	E
IV	E	Roof System													
	X_{143}	Framing & Sheathing	Truss 24" OC + 5/8 Ply + 10" ins	5											
	X_{144}		" 24" OC + 1/2 " + " "	4						x					1
	X_{145}		" 24" OC + 1/2 " + 6" "	3		x	x	x	x		x	x	x	x	8
	X_{146}		" 24" OC + 3/8 " + 6" "	2	x										1
	X_{147}		" 48" OC + 3/4 " + 6" "	1											
	X_{148}		Rafter 48" OC + 3/4 Ply + 6" insul	Std											
	X_{149}	Roofing	Clay tile or Alum shingles	5											
	X_{150}		5 Ply Build-up DR 350#	4											
	X_{151}		325#	2											
	X_{152}		300#	1		x									1
	X_{153}		235# Class C	Std	x		x			x	x	x	x		6
	X_{154}		Wood Shake					x	x					x	3
	X_{155}	Gutters, Flashing	Copper	5											
	X_{156}		Lead	4											
	X_{157}		Aluminum/GI	1	x	x	x	x	x	x	x	x	x	x	10
	X_{158}		PVC	Std											
F	X_{159}	Windows	Wood Frame, insul	5											
	X_{160}		Wood Frame	3											
	X_{161}		Alum Frame, insul	2						x	x	x			3
	X_{162}		Alum	Std	x	x	x	x	x				x	x	7

	Dwelling Unit Engineering			A	B	C	D	E	F	G	H	I	J	E
IV G	Doors													
X_{163}	Exterior	Decorative, Solid wood	4					x			x	x	x	4
X_{164}		Birch, Solid wood	2						x	x				2
X_{165}		Pine, Solid wood	Std	x		x								2
X_{166}		Metal			x		x							2
X_{167}	Interior Room/Closet	Wood finish/wood finish	5		x			x				x	x	4
X_{168}		Wood finish/metal	4			x				x	x			3
X_{169}		Painted/metal	3											
X_{170}		Hardboard/metal	2	x			x							2
X_{171}		Hardboard/Fiber	Std						x					1
		Other												
H	Kitchens													
X_{172}	Floor	Sheet vinyl over 1/8"	5											
X_{173}		" " 1/16 1/8"	4					x					x	2
X_{174}		Vinyl tile over 1/16"	2											
X_{175}		Sheet Vinyl 1/16	1		x	x			x	x	x	x		6
X_{176}		Vinyl tile 1/16	Std	x			x							2
X_{177}	Cabinets & Counters Quality/Material	Good Grade/Ceramic Tile	5											
X_{178}		Std Grade/Ceramic Tile	4											
X_{179}		Good Grade/Color Formica	2			x	x	x	x	x	x	x	x	8
X_{180}		Std Grade/Color Formica	1		x									1
X_{181}		Std Grade/Std Formica	Std	x										1
X_{182}	Exhaust Fans	Range hood-Exterior exhaust	3											
X_{183}		Exhaust fan	Std											
X_{184}		Rangehood-Interior exhaust		x	x	x	x	x	x	x	x	x	x	10

		Dwelling Unit Engineering			A	B	C	D	E	F	G	H	I	J	E
IV	H X_{185}	Kitchen sinks	Stainless steel 42"	5											
	X_{186}		" " 32/36"	4											
	X_{187}		Cast iron 42"	2											
	X_{188}		" " 32/36"	1	x	x	x	x	x	x	x	x	x	x	10
	X_{189}		Single Cast Iron	Std											
	I	Bathrooms													
	X_{190}	Floors	Terrazzo	5											
	X_{191}		Ceramic Tile	3											
	X_{192}		Sheet vinyl	1			x		x	x	x	x	x	x	7
	X_{193}		Vinyl tile	Std	x	x		x							3
		Fixtures	Fiberglass tub encl, 2 vanity												
	X_{194}		lrg sink	5					x					x	2
	X_{195}		2 vanity, lrg sink & counter	4				x							1
	X_{196}		2 vanity, lrg counter	3		x	x			x					3
	X_{197}		2 vanity	2								x			1
	X_{198}		1 vanity	1	x						x		x		3
	X_{199}		Wall hung	Std											
	X_{200}	Interior Plumbing	Copper/CI	2											
	X_{201}	Supply/Drain	Copper/ PVC	Std	x	x	x	x	x	x	x	x	x	x	10
	K X_{202}	Interior Electrical	CU/150 Amp	5											
	X_{203}	Wire/Service	CU/100 Amp	3		x						x			2
	X_{204}		AL/150 Amp	2			x		x	x				x	4
	X_{205}		AL/100 Amp	Std	x			x			x		x		4
	L	HVAC	Not Evaluated												

APPENDIX E

LISTING OF WEIGHTED ALTERNATIVES

Paragraph		Description	Alternatives			Weighted Value
I	D	Parking	Garage 2 car/unit	x_1	4x1	4
			Garage 1 car/unit	X_2	3x1	3
			Carport 2 car/unit	X_3	1x1	1
			Carport 1 car/unit	X_4	0	0
	F	Landscaping	Excellent	X_5	5x4	25
			Good	X_6	2x5	10
			Satisfactory	X_7	0	0
	G	Recreation	One/50 units	X_8	5x1	5
			One/75 units	X_9	2x2	4
			One/100 units	X_{10}	0	0
II	B	Water Dist	12"main/250' Hyd	X_{11}	5x1x1.5	7.5
			10" " /250' "	X_{12}	4x1x1.375	5.5
			10" " /300' "	X_{13}	3x1x1.250	3.75
			8" " /250' "	X_{14}	2x1x1.125	2.25
			8" " /300' "	X_{15}	1x1x1	1
			8" " /350' "	X_{16}	0	0
	C	Sanitary Sewer	PVC/Gravity	X_{17}	5x1x1.5	7.5
			Vitclay/Gravity	X_{18}	4x5x1.375	27.5
			Conc/Gravity	X_{19}	3x1x1.250	3.75
			PVC/Pump Sta	X_{20}	2x1x1.125	2.25
			Vitclay/Pump Sta	X_{21}	1x1x1	1
			Conc/Pump Sta	X_{22}	0	0
	D	Storm Drainage	Catch Basins each corner	X_{23}	5x1x1.5	7.5
			Some catch basins	X_{24}	3x5x1.25	18.75
			All open runs	X_{25}	0	0
	F	Outdoor Lightg	Max 100' interval	X_{26}	2x1x1.125	2.25
			" 150' "	X_{27}	1x1x1	1
			" 200' "	X_{28}	0	0
	H	Street System	+4' width	X_{31}	4x1x1.375	5.4
			+2' width	X_{32}	2x2x1.125	4.5
			Std Width	X_{33}	0	0
	I	Parking & Driveways	Dbl width, conc	X_{34}	3x5x1.5	22.5
			Dbl width, asph	X_{35}	2x3x1.375	8.0
			Sgl width, conc	X_{36}	2x1x1.125	2.25
			Min width, asph	X_{37}	0	0

Paragraph		Description	Alternatives			Weighted Value
II	J	Walkways	All +1' width	X_{38}	5x1x1.5	7.5
			House + 1' width	X_{39}	2x2x1.25	5.0
			Street + 1' width	X_{40}	3x3x1.125	10.125
			Std	X_{41}	0	0
	K	Ground Cover	100% sod	X_{43}	5x5x1.5	
			75% sod	X_{44}	4x2x1.375	
			50% sod	X_{45}	3x1x1.25	3.75
			25% sod	X_{46}	2x1x1.125	2.25
			All seed	X_{47}	0	0
III	B	Net Floor Area	Basic	X_{53}	0	0
			0-2% minus	X_{48}	-1x1	-1
			2-4% minus	X_{49}	-2x1	-2
			4-6% minus	X_{50}	-3x1	-3
			6-8% minus	X_{51}	-4x1	-4
			8-10% minus	X_{52}	-5x3	-15
	D	Indoor-Outdoor Integration	All 3	X_{54}	5x1	5
			Lrg Patio & Encl	X_{55}	4x1	4
			Lrg Patio & Fence	X_{56}	3x2	6
			Std Patio & Fence	X_{57}	2x2	4
			Lrg Patio	X_{58}	1x2	2
			Std Patio	X_{59}	0	0
	E	Storage	60-75% above min	X_{60}	5x4	20
			45-60% " "	X_{61}	4x1	4
			30-45% " "	X_{62}	3x1	3
			15-30% " "	X_{63}	2x1	2
			0-15% " "	X_{64}	1x1	1
			Minimum	X_{65}	0	0
	F	Vehicle Storage	2 car attchd garage	X_{66}	5x3	15
			2 car detchd garage	X_{67}	4x1	4
			1 car attchd garage	X_{68}	3x2	6
			2 car carport	X_{69}	1x1	1
			1 car carport	X_{70}	0	0
	H	Living Accomoda-tions	Builtin F.P. & Book-case	X_{72}	5x1	5
			Builtin F.P.	X_{73}	4x5	20
			Freestanding F.P. & Bookcase	X_{74}	3x1	3
			Freestanding F.P.	X_{75}	2x1	2
			Bookcase	X_{76}	1x1	1
			None	X_{77}	0	0

Paragraph		Description	Alternatives			Weighted Value
III	I	Bedroom Size	More than 20% above min.	X_{78}	5x5	25
			16-20% above min	X_{79}	4x1	4
			11-15% " "	X_{80}	3x1	3
			6-10% " "	X_{81}	2x1	2
			1-5% " "	X_{82}	1x1	1
			Min	X_{83}	0	0
	J	Bathrooms	Oversize & Additnl	X_{84}	5x3	15
			Additional	X_{85}	4x3	12
			Oversize & Extras	X_{86}	3x1	3
			Oversize	X_{87}	2x1	2
			Min	X_{88}	0	0
	K	Food Handling	Oversize & 12SF extr	X_{89}	5x2	10
			Oversize & 6SF extra	X_{90}	4x1	4
			Oversize	X_{91}	3x1	3
			6 SF extra	X_{92}	2x1	2
			3 SF extra	X_{93}	1x2	2
			Min	X_{94}	0	0
	L	Utility & Work Area	Main floor, separate room w/ storage	X_{95}	5x2	10
			Main floor, separate room w/o storage	X_{97}	4x1	4
			Basement	X_{98}	2x3	6
			Main floor encl	X_{99}	0	0
IV	A	Foundation System	Basement	X_{100}	5x4x1.5	30
			Crawl space	X_{101}	2x2x1.125	4.5
			Slab on Grade	X_{102}	0	0
	B	Floor System Construction	Steel frame, conc slab	X_{103}	5x1x1.5	7.5
			Steel frame, wood floor	X_{104}	3x1x1.25	3.75
			Wood frame, wood floor	X_{105}	2x5x1.125	11.25
			Slab on Grade	X_{106}	0	0
		Finish Flooring	Hardwood	X_{107}	5x1x1.5	7.5
			Sheet vinyl, thk	X_{108}	4x1x1.375	5.5
			Sheet vinyl, std	X_{109}	2x5x1.125	3.75
			Vinyl tile	X_{110}	2x1x1.125	2.25
			Vinyl Abs thk	X_{111}	1x1x1	1
			Vinyl Abs std	X_{112}	0	0

Paragraph		Description	Alternatives			Weighted Value
IV	C	Exterior Walls				
		Construction	Reinforced Conc	X_{113}	5x1x1.5	7.5
			Masonry	X_{114}	4x1x1.375	5.5
			Steel Frame	X_{115}	3x3x1.25	11.25
			Wood Frame	X_{116}	0	0
		Insulation	4" Fiberglass w/VB	X_{117}	5x3x1.5	22.5
			2-1/2" " "	X_{118}	3x4x1.25	15
			Vapor Barrier	X_{119}	0	0
		Sheathing	5/8" Plywood	X_{120}	5x1x1.5	7.5
			1/2" "	X_{121}	4x1x1.375	5.5
			5/8" Fiber	X_{122}	2x1x1.125	2.25
			3/8" Plywood	X_{123}	1x1x1	1
			15/32" Fiber	X_{124}	0	0
		Finishes	All Brick/Stucco	X_{125}	5x1x1.5	7.5
			1/4 Brick & 3/4 wood	X_{126}	4x1x1.375	5.5
			All wood unpainted	X_{127}	3x1x1.25	3.75
			1/4 wood & 3/4 pre-fin	X_{128}	2x3x1.125	6.75
			Prefinished	X_{129}	1x3x1	3
			Plywood	X_{130}	0	0
	D	Interior Walls and Ceilings				
		Wall Const	Reinforced masonry	X_{131}	5x1x1.5	7.5
			Unreinforced "	X_{132}	4x1x1.375	5.5
			Wood Frame	X_{133}	2x5x1.125	11.25
			Metal studs	X_{134}	0	0
		Ceiling const	Sheet rock, spray fin	X_{135}	5x5x1.5	37.5
			Sheet rock, paint	X_{136}	3x1x1.25	3.75
			Accoustical tile	X_{137}	0	0
		Wall finish	Plaster, 3 coats paint	X_{138}	5x1x1.5	7.5
			Plaster, 2 coats paint	X_{139}	4x1x1.375	5.5
			Drywall, 3 coats paint, 10% panelg	X_{140}	2x1x1.125	2.25
			Drywall, 2 coats paint, 10% panelg	X_{141}	1x1x1	1
			Drywall, 2 coats paint	X_{142}	0	0

Paragraph	Description	Alternatives			Weighted Value
E	Roof System Framing & Sheathing	Truss 24"OC + 5/8" Ply + 10" insul	X_{143}	5x1x1.5	7.5
		Truss 24"OC + 1/2" Ply + 10" insul	X_{144}	4x1x1.375	5.5
		Truss 24"OC + 1/2" Ply + 6" insul	X_{145}	3x5x1.25	18.75
		Truss 24"OC + 3/8" Ply + 6" insul	X_{146}	2x1x1.125	2.25
		Truss 48" + 3/4" Ply + 6" insul	X_{147}	1x1x1	1
		Rafter 48" OC + 3/4 Ply + 6" insul	X_{148}	0	0
	Roofing	Claytile or Alum	X_{149}	5x1x1.5	7.5
		5 Ply Built up or 350# Class "A"	X_{150}	4x1x1.375	5.5
		325#	X_{151}	2x1x1.125	2.25
		300#	X_{152}	1x1x1	1
		235# Class C	X_{153}	0	0
	Gutters & Flashing	Copper	X_{155}	5x1x1.5	7.5
		Lead	X_{156}	4x1x1.375	5.5
		Aluminum, Galv iron	X_{157}	2x5x1.125	11.25
		PVC	X_{158}	0	0
F	Windows	Wood frame, insul	X_{159}	5x1x1.5	7.5
		Wood frame	X_{160}	3x1x1.25	3.75
		Alum frame, insul	X_{161}	2x2x1.125	
		Alum frame	X_{162}	0	0
G	Doors Exterior	Decorative, solid wood	X_{163}	4x3x1.375	16.5
		Birch, solid wood	X_{164}	2x2x1.125	4.5
		Pine, solid wood	X_{165}	0	0
	Interior room & closet	Wood fin/wood fin	X_{167}	5x3x1.5	22.5
		Wood fin/metal	X_{168}	4x2x1.375	
		Painted, metal	X_{169}	3x1x1.25	3.75
		Hardboard/metal	X_{170}	2x2x1.125	4.5
		Hardboard/fiber	X_{171}	0	0

Paragraph		Description	Alternatives			Weighted Value
IV	H	Kitchens				
		Floor	Sheet vinyl, over 1/8"	X_{172}	5x1x1.5	7.5
			Sheet vinyl, 1/16 1/8	X_{173}	4x2x1.375	11.0
			Vinyl tile over 1/16	X_{174}	2x1x1.125	2.25
			Sheet vinyl 1/16	X_{175}	1x4x1	4
			Vinyl tile 1/16	X_{176}	0	0
		Cabinets & Counters	Good Grade/Cer Tile	X_{177}	5x1x1.5	7.5
			Std Grade/Cer Tile	X_{178}	4x1x1.375	5.5
			Good Grade/Upgrade Formica	X_{179}	2x5x1.125	11.25
			Std Grade/Upgrade Formica	X_{180}	1x1x1	1
			Std Grade/Std Formica	X_{181}	0	0
		Exhaust Fans	Range hood	X_{182}	3x1x1.25	3.75
			Exhaust fan	X_{183}	0	0
		Kitchen Sinks	Stainless Steel 42"	X_{185}	5x1x1.5	7.5
			Stainless Steel 32, 36"	X_{186}	4x1x1.375	5.5
			Cast iron 42"	X_{187}	2x1x1.125	2.25
			Cast iron 32, 36"	X_{188}	1x5x1	5
			Single bowl, cast iron	X_{189}	0	0
	I	Bathrooms				
		Floors	Terrazzo	X_{190}	5x1x1.5	7.5
			Ceramic Tile	X_{191}	3x1x1.25	3.75
			Sheet vinyl	X_{192}	1x5x1	5
			Vinyl tile	X_{193}	0	0
		Fixtures	Fiber tub encl, 2 vanity, lrg sink	X_{194}	5x2x1.5	15.0
			2 vanity, lrg sink, counter	X_{195}	4x1x1.375	5.5
			2 vanity, lrg cntr	X_{196}	3x2x1.25	7.25
			2 vanity	X_{197}	2x1x1.125	2.25
			1 vanity	X_{198}	1x1	1
			Wall hung	X_{199}	0	0

Paragraph		Description	Alternatives			Weighted Value
IV	J	Interior Plumbing	Copper/CI	X_{200}	2x1x1.125	2.25
			Copper/PVC	X_{201}	0	0
	K	Interior Electrical	CU/150 Amp	X_{202}	5x1x1.5	7.5
			CU/100 Amp	X_{203}	3x2x1.25	7.5
			AL/150 Amp	X_{204}	2x3x1.125	6.75
			AL/100 Amp	X_{205}	0	0

APPENDIX F

COMMENTS ON THE INTEGER PROGRAM

The program selected for testing the model was obtained from the University of Colorado Computing Center Library. It is titled "Arriba" and is designed to solve integer problems by any of three different algorithms chosen by the user.[1] The user manual contained in the library is labeled Preliminary however the primary author, R. E. Woolsey, confirmed that a final manual had not been issued.[2]

The "Arriba" manual did not contain sufficient information to use the program and contained several errors on the punching of control cards. In addition the manual does not provide information on the size and shape of the problems that can be solved or the form of the answers. These deficiencies severely complicated the testing and evaluation of the model. The additional user instructions contained in this appendix have also been provided to the University of Colorado Computing Center for use with the user manual.

The Arriba program, which consists of the program Arriba, eighteen subroutines and two functions, is dimensioned for a problem 100 columns by 100 rows including the right hand constraint column and objective function row. The number of rows in a problem will generally have to be less than this since each equality constraint generates two rows in the solution problem. A problem formulated

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[1] R. E. Woolsey, Brady Holcolm and Peter Ryan, <u>Arriba An All Integer Programming System</u> (Control Data Corporation, 1969).

[2] Private conversation with R. E. Woolsey, Golden, Colorado, July 8, 1975.

with an objective function, 4 less than or equal constraints and 4 equality constraints will therefore use 13 rows of the matrix. The printout will list the problem as having 13 rows rather than the 9 entered. The following cards are required to use the program:

Card 1A There is no reference in the manual to the first control card required to use the program. The main program relies on a number of computed "go to" and arithmetic "if" statements for transportation through the program. The first control card, read in 13A6 format provides the entries for one side of the arithmetic "if" statements. The user has an option on defining some of the 13 literals while others are defined elsewhere in the program. Each entry has a specific purpose as listed:

Col	Purpose	Entry Used	User Option
1-6	Matches col 1-6 on Controls card	CONTRO	Yes
7-12	Matches col 1-6 on Title card	TITLE.	Yes
13-18	Matches col 1-6 on Row ID card	ROW ID	Yes
19-24	Matches col 1-6 on End of Record cards	RECORD	Yes
25-30	Matches col 1-6 on Matrix card	MATRIX	Yes
31-36	Matches col 7-12 on cards with less than or equal constraint. Number of spaces must be consistent with constraint card.	++++++	No
37-42	Matches col 7-12 on cards with greater than or equal constraint. Number of spaces used must be consistent with constraint card.	------	No
43-48	Matches col 1-6 on algorithm card if IPSC algorithm used.	IPSC..	No
49-54	Matches col 1-6 on algorithm card if BALSAG algorithm used.	BALSAG	No
55-60	Matches col 1-6 on algorithm card if PRIMAL PRIMAL algorithm used.	PRIMAL	No
61-66	Matches col 1-6 on Arriba card	ARRIBA	No
67-72	Matches col 1-6 on Exit card	RECORD	Yes

73-78 Matches col 1-6 on Basis card BASIS. Yes

The successful use of the program depends entirely on the entries on this first card matching exactly the entry on the referenced card.

Card 1B This controls card provides directions for printing the input data, the objective value and activity list at various interations and set the pivot limit on the number of iterations allowed. The directions in the users manual for this card provide some incorrect column numbers. The correct format is as follows:

Col	
1-6	Match col 1-6 on control card 1A
15	Use either 0, suppress printing of input data or 1, print input data.
32-35	Specifies how often the objective value is printed.
56-60	Specifies how often the values of the variables are printed.
73-80	Specifies the allowable number of pivots.

Card 2 The first 6 columns of this title card must match col 7-12 on Card 1A hence "TITLE." is recommended. The remaining 74 columns are for the title of the problem and are printed at the top of the output page.

Card 3 The first 6 columns of this card must match col 13-18 on card 1A. Since this card signals the start of the listing of row constraints "ROW ID" is recommended. The constraints in col 7-12 of the row ID cards must match the respective entries in col 31-36 or 37-42 as appropriate. Anything else will be read as an equality.

Card 4 The manual refers to this card as an End Of Record (EOR) card

since it signals the end of the row constraints however the use of a 7-8-9 card, normally used for an EOR, is inappropriate. The 6 alpha-numeric characters in cols 1-6 of this card must match col 19-24 on card 1A.

Card 5 The first 6 columns of this card must match col 25-30 on card 1A. Since this card signals the start of the matrix body "MATRIX" is recommended.

Card 6 This EOR card must be the same as card 4.

Card 7 This card is optional. The first 6 columns on this card must match col 73-78 on card 1A. Since it signals the start of an initial basic solution "BASIS." is recommended.

Card 8 This EOR card is used only if a Basis is used and must be the same as Card 4.

Card 9 The first 6 columns of this card specifies the algorithm to be used. The entry must match the appropriate entry on Card 1A.

Card 10 The first 6 columns of this card must match col 61-66 on Card 1A and should be the word "ARRIBA."

Carl 11 The Arriba card signals the end of a problem and the computer will look for another problem. To terminate the program smoothly after the last problem an exit card is used. Because the program is still using arithmetic "if" statements col 1-6 of this card must match col 67-72 on Card 1A. If successful the last statement on the print out should be "All problems processed, hasta luego."

The algorithm used for the model problem was BALASG, which uses the Balas zero-one algorithm. The problem was one of maximization and it was anticipated that the output would show the objective function increasing with each iteration and the variables in the basis with a value of one. The results however were exactly the opposite. The algorithm appears to treat the problem as a minimization with the objective value printed on the output decreasing with each iteration. However this is not the desired value. The actual solution set consists of the variables with a value of zero and the value of the corresponding objective function must be calculated by summing up the respective coefficients in the objective row.

In the development of the scoring system the alternatives representing the minimum acceptable standard were assigned a coefficient of zero and it was assumed they would play no part in the maximization process, in practice this did not prove to be true because of the minimization process discussed above. As a result the original solution set included either one or two zeros for each feature evaluated. This was confusing because the formulation permitted only one alternative per feature.

To test the model therefore each coefficient in the objective function was increased by one including those with an initial value of zero. This reduced the number of variables in the solution set to the number of features evaluated.

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